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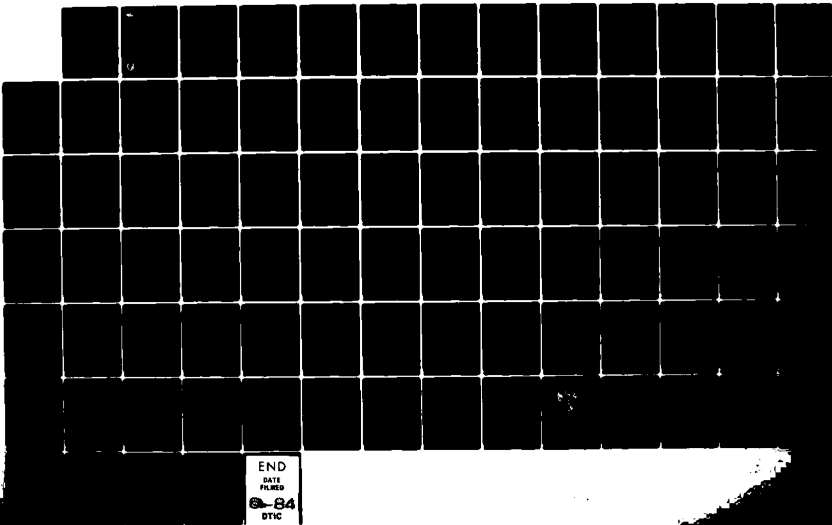

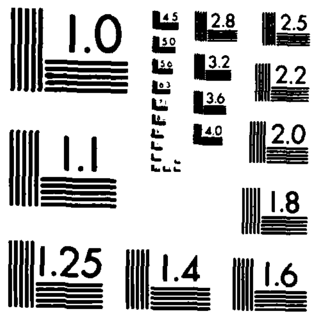

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SURVEY OF URBAN METEOROLOGICAL DATA

January 1984

By

Patrick A. Haines

University of Dayton
Research Institute
Dayton, Ohio

Under Contract DAAD07-80-D-0206
Contract Monitor: Gary McWilliams

US Army Electronics Research and Development Command
Atmospheric Sciences Laboratory
White Sands Missile Range, NM 88002

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Uppsala Urban Meteorological Project
Regional Air Monitoring System (RAMS)

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The literature was surveyed for observational studies dealing with the effect of the urban boundary on the atmospheric boundary layer. The studies are summarized according to the quantity and quality of wind, temperature, relative humidity, and turbulence data. In addition, urban areas with limited urban data are listed. From the various studies, the data arising from the Regional Air Pollution Study (RAPS) in St Louis and the Uppsala Urban Meteorological Project (UUMP) were selected for incorporation in an urban meteorological data base.

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20. ABSTRACT (cont)

RAPS and UUMP data were procured. The land use of both areas was classified according to a scheme that is meteorologically based.

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PREFACE

This report was prepared by the University of Dayton Research Institute (UDRI) for the US Army Atmospheric Sciences Laboratory (ASL) for work performed during the period of June 1982 to January 1983. The described work included reviewing the meteorological literature for urban meteorological data that resolves the urban effect on wind, temperature, humidity, and turbulence in the atmospheric boundary layer. In addition, a land use classification scheme for linking the nature of the urban boundary to its effect on the boundary layer was constructed. The scheme is discussed and results of the classification given.

The contract technical officer for this work was Gary McWilliams of ASL. Work performed at UDRI was under the administrative supervision of Nicholas A. Engler and the technical supervision of James K. Luers. The author is indebted to John Keller, Paul Huffman, and Chiu-wing Tsui of UDRI for technical assistance. Nahla Abdelnour prepared the manuscript. The author gratefully acknowledges the important contributions of all mentioned above.

The author also gratefully acknowledges the assistance and information from the following people who helped to make this report possible.

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EXORDIUM

An urban effect upon the city climate has been known for some time.[1] Early observers in the past century, such as Luke Howard in London, noted that urban areas were often warmer than nearby rural areas; later this effect became known as the heat island.[2] The urban effect on the boundary layer is considerably more complicated than simple temperature differences, however, the full range of effects, especially in regard to diffusion and dispersion of pollutants, continues to require better understanding.

Other effects include the urban heat plume,[3] enhanced turbulent diffusion, increased precipitation,[4] [5] [6] [7] ..tardation of frontal passages,[8] and reduced visibility.[9] The urban plume i lves convection and advection of warmer urban air downstream. The roug urban boundary together with enhanced

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[1]H. E. Landsberg, 1981, The Urban Climate, Academic Press, New York

[2]F. S. Duckworth and J. S. Sandberg, 1954, "The Effects of Cities upon Horizontal and Vertical Temperature Gradients," Bull Am Meteorol Soc, 35(5):198-207

[3]J. F. Clarke, 1969, "Nocturnal Urban Boundary Layer over Cincinnati, Ohio," Mon Wea Rev, 97:582-589

[4]S. A. Changnon, Jr, 1968, "The LaPorte Weather Anomaly: Fact or Fiction?" Bull Am Meteorol Soc, 49:4-11

[5]S. A. Changnon, Jr, 1969, "Recent Studies of Urban Effects on Precipitation in the United States," Bull Am Meteorol Soc, 50:411-421

[6]S. A. Changnon, Jr, 1979, "Rainfall Changes in Summer Caused by St. Louis," Science, 205:402-404

[7]F. A. Huff and J. L. Vogel, 1978, "Urban Topographic and Diurnal Effects on Rainfall in the St. Louis Region," J Appl Meteorol, 17:565-577

[8]T. Loose and R. D. Bornstein, 1977, "Observations of Mesoscale Effects on Frontal Movement Through an Urban Area," Mon Wea Rev, 105:563-571

[9]A. Hufty, 1970,"Les Conditions de Rayonnement en Ville, In Urban Climates," WMO Technical Note No 108, 65-69

convection profoundly affects the mesoscale wind flow[10] [11] and attendant turbulence levels.[12] As a result, turbulent diffusion is very different in urban areas than in rural areas. Interest in understanding and ameliorating these effects is, thus, understandably great.

The difference between rural and urban observations can arise not only from the effects of the urban boundary layer but also from the effects of complex terrain.[1] For many cities, the urban effect may be masked by other effects such as local winds and temperatures due to complex terrain or the sea breeze. It is thus highly desirable to examine cities in which the urban effect can be unambiguously ascribed as urban. Once the effect of the urban boundary is well understood, the problem of unraveling the combined urban and complex terrain effects can be undertaken.

The literature of urban climatology is vast,[13] [14] [15] ranging from numerous observational studies of the heat island to ambitious attempts to model the mesoscale flow effects of the urban boundary layer. Embedded within this literature are several large well conceived observational programs designed to resolve the full range of urban boundary layer effects. This report is concerned with identifying these observation programs. Table 1 identifies the cities that have been surveyed and the data collected.

While a large number of urban data bases were examined, there are few that meet the specific goals of this study. These goals involve the type of urban area for which the measurements were made, as well as the number and duration of measurements. For the purposes of this study, an urban area is a populated area that causes an observable effect on the atmospheric boundary layer.

---

[10] J. K. Angell et al, 1973, "Urban Influence on a Strong Daytime Flow as Determined from Tetroon Flights," J Appl Meteorol, 12:924-936

[11] D. O. Lee, 1979, "The Influence of Atmospheric Stability and the Urban Heat Island on Urban-Rural Wind Speed Differences," Atmos Environ, 13:1175-1180

[12] H. Melling and R. List, 1980, "Characteristics of Vertical Velocity Fluctuations in a Convective Urban Boundary Layer," J Appl Meteorol, 19(10):1184-1195

[1] H. E. Landsberg, 1981, The Urban Climate, Academic Press, New York

[13] T. J. Chandler, 1970, "Selected Bibliography on Urban Climate," WMO Publication 276, TP 155

[14] T. R. Oke, 1974, "Review of Urban Climatology, 1968-1973," WMO Publication Technical Note 134

[15] T. R. Oke, 1979, "Review of Urban Climatology, 1973-1976," WMO Publication Technical Note 169

TABLE 1

DATA COLLECTED IN URBAN OBSERVATIONAL PROGRAMS

Observation Program	Sf_c	V	T	RH	Rad	Vertical	V	T	RH	MH*	Turb.	Duration	Sites
St. Louis-RAPS		x	x	x	x		x	x	x	x	x	8/74 - 5/77	25 sfc., 4 UA
St. Louis-Metromex		x	x	x	x		x	x	x	x		1971 - 1975	26 sfc., 15 UA
New York APP		x	x	x			x	x				1964 - 1969	97 sfc., 28 UA
Uppsala, Sweden		x	x	x	x		x	x	x	x	x	1974 - 1978	7 sfc., 4 UA
Edmonton, Alberta		x	x	x	x		x	x		x	x	11/74 - 12/74	3 sfc., 5* UA
Calgary, Alberta		x	x	x			x	x		x		9/74 - 6/75	28 sfc., 1 UA
Las Vegas, Nevada		x	x				x	x				1975 - 1977	14 sfc., 2 UA
Columbus, Ohio			x				x	x			x	6/68 - 3/69	several UA
Oklahoma City, Ok.							x	x				9/71 - 10/71	1 UA
Austin, Texas			x				x	x				1972	2 UA
Johannesburg, S.A.		x	x	x			x	x		x		1970 - 1972	3 sfc., 7 UA
Montreal, Quebec		x	x	x	x		x	x				1969 - 1970	3 sfc., 14 UA
Fort Wayne, Indiana		x	x				x	x				1964 - 1966	10 sfc., 5 UA
Cincinnati, Ohio			x				x	x				5/67 - 2/68	traverses, several UA
Christ church, N.Z.			x				x	x				1 night, 197?	120 sfc., 2 UA
Dayton, Ohio		x	x	x	x							1977 - 1978	8 sfc., 2 UA
Vienna, Austria		x	x									1968 - presnt	26 sfc.
Hamilton, Ont.			x				x	x				1965 - 1966	200 sfc., 1 UA
Denver, Colorado		x	x									12/64 - 4/65	20
Giessen, Germany			x									----	6
Dallas, Texas			x	x	x							1967	sfc. traverses
Denton, Texas			x									1967	sfc. traverses
San Jose, California			x									1967	sfc. traverses
Minneapolis, MN		x	x				x	x				12/77 - 3/79	14 to 19 sfc., 1 UA
Cheyenne, Wyoming		x	x									12/77 - 3/79	6 sfc.
Greeley, Colorado		x	x				x	x				12/77 - 3/79	7 sfc., 1 UA
Louisville, Kentucky		x	x	x			x					7/56 - 12/56	5 sfc., 2 UA
Regina, Saskatchewan		x	x	x	x							many years	1 sfc.
Saskatoon, Sask.		x	x	x								many years	1 sfc.
Tampa, Florida		x								x		1931 --1967	2 sfc.
Johnstown, Pa		x	x	x			x	x				7/64 - 2/66	1 sfc., 3 UA
Freiburg, Germany		x	x	x				x		x		----	2 sfc., 1 UA
Los Angeles, Cal.		x	x	x	x		x	x				recent years	35 sfc., 15 UA
Milwaukee, Wisconsin		x	x									1979 - 1980	4 sfc.
Paris, France		x	x	x	x							many years	9 sfc.
Toronto, Ontario			x				x	x				several years	5 UA
Omaha, Nebraska		x	x	x	x								NWS
Poona, India			x										traverse
Bombay, India			x										traverse
Plymouth, England			x									4 days, 3/73	11 sfc.
Helsinki, Finland			x									3 days, 2/73	traverses
Brisbane, Australia		x	x	x			x	x	x				3 sfc., 1 UA
Portland, Maine		x	x	x								several years	2 sfc.
Kansas City, MO			x									6/71 - 10/72	traverses
Albuquerque, N.M.		x	x	x								several years	4 sfc.
San Francisco, Cal.		x	x	x	x		x	x	x			1969 - 1982	32 sfc., 1 UA
Cleveland, Ohio		x	x	x	x							several years	2 sfc.
South Bend, Indiana		x	x	x	x							several years	1 sfc.
Rome, Italy		x	x	x			x	x	x			several years	18 sfc., 1 UA
Cologne, Germany								x		x		6/78 - 6/80	3 UA
Mexico City, Mexico		x	x									several years	30 sfc.
Halifax, Nova Scotia		x	x	x	x							several years	1 sfc.
Sydney, Nova Scotia		x	x	x	x							several years	1
Washington, D.C.		x	x	x	x		x	x	x			several years	250 sfc., 1 UA
Charlotte, N.C.		x	x	x	x							several years	1 sfc.
Toledo, Ohio		x	x	x	x							several years	2 sfc.
Chattanooga, Tenn.		x	x	x	x							several years	1 sfc.
Wichita, kansas		x	x	x	x							several years	1 sfc.
York, Pennsylvania		x	x	x	x							several years	1 sfc.
Duluth, Minnesota		x	x	x	x							several years	1 sfc.
Seattle, Washington		x										several years	5 sfc.
Adelaide, Australia		x	x	x								several years	11 sfc.
Tuscon, Arizona		x	x	x	x							several years	1 sfc.
Nashville, Tennessee		x	x	x	x							several years	1 sfc.
Tallahassee, Florida		x	x	x	x							several years	2 sfc.
Miami, Florida		x	x	x	x							several years	2 sfc.
Winnipeg, Manitoba								x				1 year	1 UA
Venice Italy		x										2/73 - 4/73	3 sfc.
Utrecht, The Neth.		x	x	x	x		x	x	x			12/69 - 2/70	2 sfc., 2 UA
Stuttgart, Germany		x	x									several years	7 sfc.
Tsukuba, Japan		x	x	x	x							since 1977	1 sfc.
Tokyo, Japan			x				x					several years	12 sfc., 1 UA
Nagano, Japan			x									11/8-11/13 72	38
Koide, Japan			x					x				11/4-11/12 69	200 sfc., 1 UA
Liege, Belgium		x	x									1962	8 sfc.
London, England		x	x	x			x	x				several years	5 sfc., 4 UA
Chapel Hill, N.C.				x								auto	traverse
Columbia, Maryland			x	x								1967 - 1975	8 sfc.
Asahikawa, Japan			x	x									10 sfc., 2 UA

Note: UA - Upper Air / MH - Mixing Height

PURPOSE OF THE SURVEY

As complete a survey as possible has been done on observational programs dealing with the urban boundary layer. The scope of the various programs varies widely. Some programs have been primarily concerned with resolving the low-level heat island under optimum conditions. Observations mainly consisted of temperatures obtained during auto traverses of an urban area. Other programs have attempted to study the spatial and temporal development of the urban boundary layer. A variety of devices including balloons, lidars, radars, instrumented aircraft, towers, and tracer releases have been used. The initial purpose of this survey is the identification of programs that resolve the full urban boundary effect. The required measurement programs should incorporate seasonal and diurnal variation, incorporate a large variety of observations, and offer detailed spatial and temporal resolution. The variety of observations includes surface measurements of wind, temperature, relative humidity, cloud cover, and solar radiation. It also includes vertical profiles of wind, temperature, relative humidity, and turbulence to an altitude of at least 1000 m. Programs with large amounts of vertical observations, especially from towers or balloons at several sites are the most desirable.

Of additional importance is the condition and availability of the data. An urban data base incorporating data from the most complete programs is planned. Ease in the access of data is a strong criterion. Programs in which the data has been or may be archived on magnetic tape should take precedence. The most important criterion is whether or not the data is available.

A land use study of urban areas of selected observational programs was also done. The planned data base will incorporate both the meteorological observation and the land use classes of the area in which the observation was made. The land use class is based on a consideration of the roughness and radiative characteristics of the urban surface. Eventually it is hoped to attribute the urban effect to the effects the various types of urban land use have on the atmospheric boundary layer. As such, it will be possible to infer the meteorological conditions within an urban area by knowing the conditions in the surrounding countryside and the land use classification of the urban area.

The following report consists of several sections. In the first section the various urban meteorology study programs are described. From these programs the Regional Air Pollution Study (RAPS) in St. Louis and the Uppsala Urban Meteorological Project (UUMP) were selected for initial incorporation into the urban meteorological data base. Justification for this selection follows the descriptions section. The land use was classified in both Uppsala and St. Louis. Both the classification method and its implementation to Uppsala are described in the section on land use classification.

URBAN METEOROLOGY OBSERVATION PROGRAMS

In this section, the various programs of observation of the urban boundary layer are described. The section is segmented into three parts. In the first part the largest and most complete programs are described. These programs are distinguished chiefly by the vertical resolution of the collected data. Incorporation of data from some of these programs into a data base would be desirable. The second part includes programs in which little or no vertical data was collected or where data has been collected for several unrelated programs. Incorporation to the data base of data from these programs would be either undesirable or present insuperable problems. In the final part, cities having few urban meteorological observations are listed.

Larger Programs

Adelaide, Australia
Asahikawa, Japan
Austin, Texas
Calgary, Alberta
Christchurch, New Zealand
Cincinnati, Ohio
Columbus, Ohio
Edmonton, Alberta
Fort Wayne, Indiana
Hamilton, Ontario
Johannesburg, South Africa
Las Vegas, Nevada
Louisville, Kentucky
Montreal, Quebec
New York, New York
St. Louis, Missouri
  RAPS
  METROMEX (Metropolitan Meteorology Experiment)
Uppsala, Sweden

Adelaide, Australia

Adelaide (latitude 34°56'S and longitude 138°35'E), the state capital of South Australia with a population of 700,000, is situated with the greater part of the city located on a coastal plain adjacent to the Mount Lofty Ranges. Although these ranges present steep scarps to the Adelaide plains they are of comparatively low altitude. Mount Lofty, the highest peak is 726 m above mean sea level.

The urban boundary layer was studied at Adelaide using both fixed and mobile observations.[16 17] Fixed observations of temperature and windspeed and wind direction were obtained from a network of urban stations sited so as to be representative of their locations. The temperature data were recorded on Lambrecht thermo-hygrographs mounted in small Stevenson screens, whereas the wind data were recorded on Lambrecht Woelfle anemometers mounted on 10-m towers. These data are supplemented by Bureau of Meteorology observations.

Vertical wind and temperature data was collected on a 47.5 m tower located southeast of the central business district. The tower site is only a few meters from Main South Road which crosses Adelaide from north to south. Industry is confined to a narrow strip which is no wider than 500 m and usually 50 to 150 m wide on either side of the road. The industrial buildings are generally 10 to 15 m high. Beyond the industrial strip there is extensive and uniform suburban development. Houses are about 10 m high surrounded by gardens and trees.

Observations were made during 78 days in 1977 and 1978 and were made during all seasons of the year. Instrumentation consisted of fast response sensors for horizontal wind (vane mounted Gill anemometers), vertical wind (Gill propeller anemometer), temperature (bead Thermistor STC-U23), and humidity (infrared absorption hygrometer). In addition, the approximate surface temperature was measured. Eight variables were recorded every 30 s on digital cassette tape. Raw data has been stored on magnetic tape generated on a DEC SYSTEM 10 computer.

Temperature was also measured during city traverses using a perspex lagged thermistor probe mounted on a vehicle. The probe had a time constant on the order of 1 min. This lagging produced a smooth record and reduced variations caused by abrupt changes in the vehicle's speed due to traffic conditions. It also overcame the problem of small scale horizontal variability. No artificial aspirator was provided.

The temperature sensors were mounted in radiation shields and these were positioned on a Mazda van. The van had provision for the measurement of both wet and dry-bulb temperatures at two levels, but in this study only the upper level sensors were used and both were maintained as dry-bulb sensors. Power was supplied via a Honda generator mounted at the rear of the van and all recording was carried out on a six-channel Rikadenki recorder mounted inside the vehicle.

---

[16] P. A. Coppin, 1979, "Turbulent Fluxes over a Uniform Urban Surface," PhD Thesis, Research Report 31, The Flinders University of South Australia, Adelaide, Australia

[17] P. Schwerdtfeger and T. J. Lyons, 1976, "Wind Field Studies in an Urban Environment," Urban Ecology, 2:93-107

Throughout the traverses, the Mazda van always followed another vehicle carrying a visibility meter. In this way the van mounted generator could have no effect on the visibility meter and the front radiometer was not influenced by the preceding vehicle because the two vehicles were separated.

In order to eliminate, as far as possible, all effects except the general features of the urban climate, traverses were only carried out on clear nights with light geostrophic winds. In each case anticyclones were either passing over or had just passed over the Adelaide region. Relative humidity on each of the nights was always less than 70 percent, which implied that the visibility readings would not be significantly affected by the growth of hygroscopic particles.

Asahikawa, Japan

Asahikawa is located on the northern Japanese island of Hokkaido. It lies in a valley surrounded by hills and mountains whose elevations range upwards to 900 m. The highest hills are to the southwest. Being in a valley, the city is subject to fog and pollution problems, especially during the cold season months. The city has 350,000 inhabitants in an area of about 60 km^2. It is located at 43°46' north latitude and 142°22' east longitude.

Measurements of windspeed and wind direction have been taken 24 times[18] a day at five urban locations since 1975. The locations of the wind sites are indicated in figure 1. Vertical profiles of wind and temperature were taken by a low level radiosonde at locations 1 and 6 on the map. Auto traverses were made to delineate the horizontal variation of surface temperature. Rural measurements of temperature, wind, and sunshine duration have been made daily since 1950 at five locations also shown on the map. Measurements were also made at the Asahikawa Meteorological Observatory.

Austin, Texas

Observations were taken during the winter and summer of 1972.[19] [20] Instruments were mounted on two towers, one at a suburban site and one at an urban site in the center of the city. At the suburban site, observations were taken in both the summer and winter, but only during the summer at the urban site. Windspeed and wind direction, temperature, roughness parameter as a function of mean direction deviation, intensity of turbulence as a function of mean wind direction deviation, standard deviation of the horizontal wind direction, and cloud cover were observed.

---

[18]K. Sakurai, 1982, "Relation Between the Air Pollution and the Meteorological Condition at Asahikawa," Journal of the Faculty of Science, Hokkaido University Series VII, 6(1):115-125

[19]J. L. Wood, 1971, The Nocturnal Urban Heat Island in Austin, Texas. Atmos Sciences Group, Report 28, University of Texas, Austin, TX

[20]J. Reschier Jr., 1973, Wind and Temperature Profiles in an Urban Area. Atmospheric Sciences Group, Report 33, University of Texas, Austin, TX

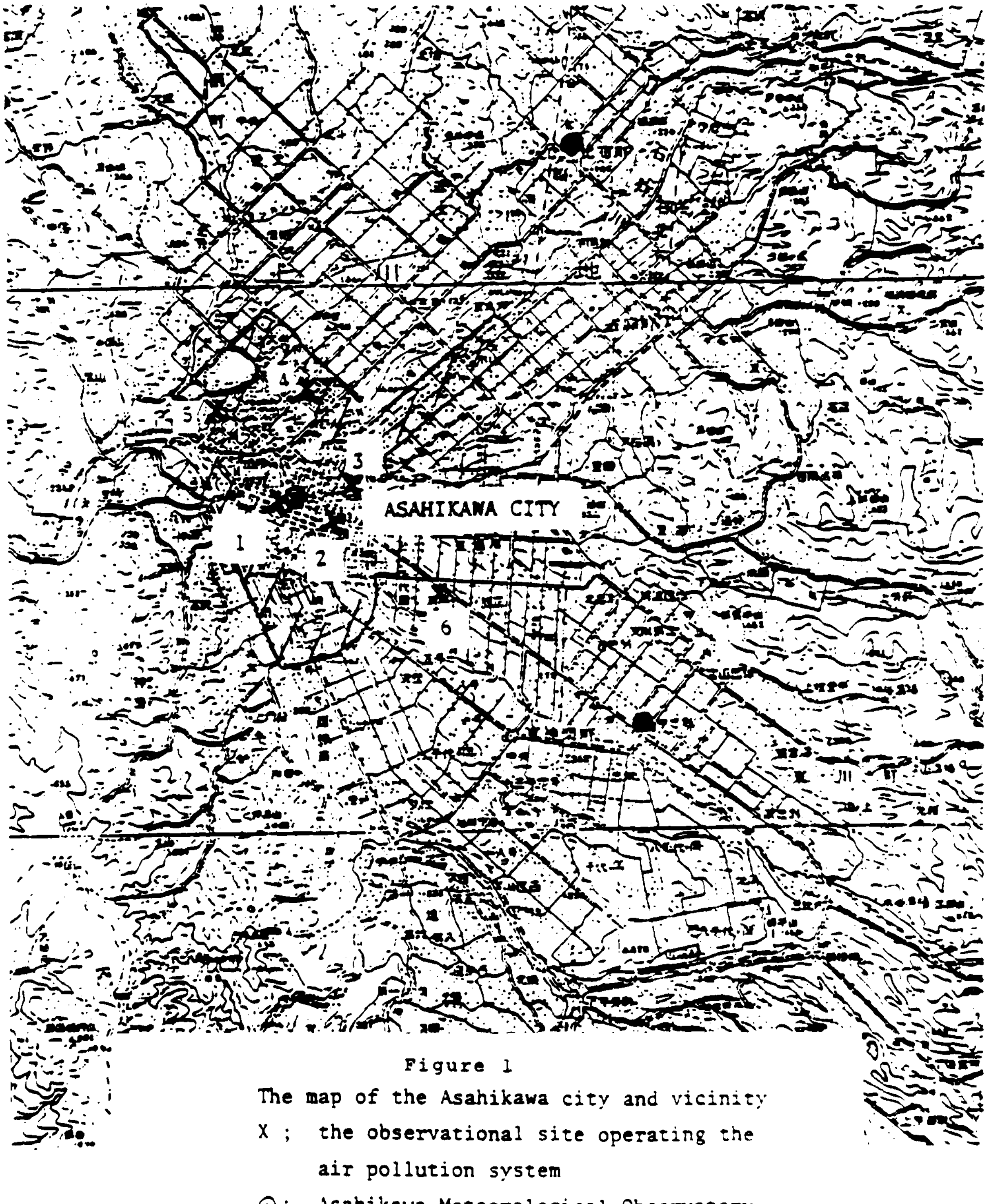

Figure 1

The map of the Asahikawa city and vicinity

X ; the observational site operating the air pollution system

⊙; Asahikawa Meteorological Observatory

● ; the station operated by AMO

The shadowing area in the map is urban

Windspeed, wind direction, and temperature were measured at 6, 10, 16, 27, and 44 m at both urban and suburban sites. Averages and standard deviations of windspeed, wind direction, temperature, and intensity of turbulence were also calculated. Data measured by wind and thermolinear instruments were taken every 20 s, that is, three samples per minute.

Instruments

Wind set

Gill Microvane and 3-cup anemometer (R. M. Young Company, Traverse City, Michigan)

Thermolinear Instruments

YSI Part #44202 thermistors (Yellow Springs Instrument Co., Yellow Springs, OH 45387)

Precision Instrument 6100 magnetic tape recorder.

Location:

Both the wind instruments and thermolinear instruments were located at 6, 16, 27, and 44 m at both the urban and suburban sites.

Specification:

The wind instruments used were Gill Microvane and 3-cup anemometers (R. M. Young Company, Traverse City, Michigan). The vanes and anemometers were calibrated prior to installation. The microvanes have a delay distance (50 percent recovery) of 3.1 ft and a dampening ratio of 0.44. The 3-cup anemometers have a distance constant (63 percent recovery) of 8.0 ft. The threshold velocity was approximately 1.1 mph or 0.5 mps.

The thermolinear temperature measuring network consisted of YSI Part #44202 thermistors (Yellow Springs Instrument Co., Yellow Springs, OH 45387). The absolute accuracy was ±0.15°C and the time constant (63 percent response) in still air. The design range of temperature measurement was -5°C to +45°C.

AVAILABLE DATA AND ANALYSIS PROCEDURE

General Features

The data were gathered in the afternoon under neutral to unstable conditions. The cloud cover was generally clear to partly cloudy in all cases. Data were gathered for the following times at the indicated sites:

41st and Speedway -- Site 1

Winter		Summer	
21 Feb 72	1130-1530 CST	22 May 72	1200-1505 CDT
22 Feb 72	1155-1540 CST	26 Jun 72	1500-1700 CDT
1 Mar 72	1455-1620 CST	27 Jun 72	1500-1715 CDT
2 Mar 72	1103-1530 CST	20 June 72	1023-1450 CDT

4th and Nueces -- Site 2

Winter		Summer	
		1 Aug 72	1220-1510 CDT
	No winter data	9 Aug 72	1240-1640 CDT
		16 Aug 72	1335-1650 CDT
		18 Aug 72	1250-1710 CDT

The wind directions generally encountered were from the east through south. The particular dates and times chosen were dependent on the synoptic conditions, and availability of personnel to monitor the equipment. When the synoptic conditions indicated average windspeeds of over 2 mps at the 6-m level, and when personnel were available, then the equipment van was sent to record data. Convective shower conditions were avoided so that the wind data recorded were not of the short-lived downdraft type. Also, equipment maintenance and repair excluded a few days of measurement.

Data is available from:

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College of Engineering
University of Texas
Austin, Texas
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Calgary, Alberta

Calgary has a population of roughly 500,000 and occupies a land area of about 260 km^2 at latitude 51°N and longitude 114°W. During the time frame from 1974 to 1978 a number of meteorological observations were carried out using surface stations, tower measurements, minisonde soundings, and automobile transects.[21 22]

Temperature and relative humidity were recorded at 28 surface stations using hygrothermographs that were intercalibrated and checked weekly. Windspeed was measured at a height of 10 m from a downtown parking lot.

Vertical profiles were obtained from two towers at 50-m intervals to a height of 300 m. One of the towers used was the Bonnybrook tower located in Ogden about 3 km southeast of the downtown area. The other tower used was part of the Canadian Tower Network. These tower measurements were supplemented by over 100 minisonde soundings of temperature and wind velocity, helicopter soundings, and accoustic soundings. The minisondes were launched at two locations at the nominal times of 0700 and 1500 local standard time (LST).

In addition to the fixed station and vertical profile measurements, a large number of mobile transects were made to obtain temperature and wind velocity at a height of 10 m.

Data relevant to this program is on magnetic tape, copies of which are available.

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Christchurch, New Zealand

Christchurch is situated on the eastern margin of the Canterbury Plains. It is an ideal site for the testing of an urban energy balance model since the area is flat and the land use relatively uncomplicated.

Urban temperatures were collected in the early afternoon and evening at 120 sites on approximately 1-h car traverses of the Christchurch area.[23] All temperatures were taken with whirling psychrometers at screen height and standardized to 1400 and 2230 values. During the traverses urban and rural tethered balloon data were collected and pilot balloons released.

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[21]L. C. Nkemdirim, 1977, "Research in Urban Climatology at the University of Calgary," extract from Climatological Bulletin 22:19-23, McGill University, Montreal, Canada

[22]L. C. Nkemdirim and P. Truch, 1978, "Variability of Temperature Fields in Calgary, Alberta," Atmos Environ, 12:809-822

[23]N. J. Tapper et al, 1981, "Modeling the Winter Urban Heat Island over Christchurch, New Zealand," Appl Meteorol, 20:365-376

Land use for each of 250 1 km^2 grid squares was determined from aerial photographs. There were 12 land use categories and for each, values of surface roughness, heat capacity, albedo, thermal conductivity of the substrate, and evaporating fraction were assigned. Transmissivities were then used for assigning to each square a specific transmissivity to account for attenuation of solar radiation by air pollution. Initial substrate soil temperatures were held constant and the values of thermal conductivity and heat capacity were assumed constant with depth.

Urban boundary layer lapse rates and wind profiles were measured using modified radiosonde equipment flown on a tethered balloon and using pilot balloons. Data is limited to one observation day.

Cincinnati, Ohio

Thirteen field investigations of the nocturnal temperature and wind structure of the urban boundary layer were conducted in the Cincinnati, Ohio area between 23 May 1967 and 6 February 1968.[3]

The field investigations were conducted just before sunrise along a path paralleling the airflow in the lower layers. They consisted of vertical temperature profiles measured at several sites with a helicopter, vertical profiles of the horizontal wind by single theodolite pilot balloon ascents, and temperatures near the surface obtained by means of automobile traverses across the city. The data is not available on magnetic tape.

Columbus, Ohio

Columbus, Ohio in 1968 had a population in excess of 580,000 while the metropolitan area had a population in excess of 865,000.

The Columbus experimental program was conducted in June 1968, September 1968, and March 1969. There were four measuring periods in September 1968 and five during March 1969. During the experimental periods, measurements commenced just before sunset and continued until sunrise with a break at 0100 to 0400 LST. Details of the data collection are from McElroy.[24]

> "1) Vertical profiles of dry- and (usually) wet-bulb temperature were obtained by telethermometers which consisted of thermistors in Wheatstone bridge circuits and were of in-house design and construction. The thermistor probes were housed midway in a radiation shield consisting of two concentric aluminum tubes separated by styrofoam insulation. The probes were mounted on a skid of the helicopter, and sampling was conducted at a forward speed of 20 to 30 m/s to minimize the effect of air movement

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[3] J. F. Clarke, 1969, "Nocturnal Urban Boundary Layer over Cincinnati, Ohio," Mon Wea Rev, 97:582-589

[24] J. L. McElroy, 1971, "An Experimental and Numerical Investigation of the Nocturnal Heat Island over Columbus, Ohio," unpublished PhD Thesis, The Pennsylvania State University, Pittsburgh, PA

induced by the rotor. Temperature to the nearest 0.1°F was recorded manually after a level traverse of about 13 s at each selected altitude and location to allow for lag in the response of the thermistors; the time constant is roughly 4 s, and the absolute accuracy of the instrument is 0.5°F.

"Helicopter flights across the metropolitan area originated at 2-h intervals and lasted between 45 and 80 min. The flights were conducted as closely as possible along a path in line with the mean wind direction in the lowest 50 to 100 m. During the flights, ascents were made at four to eight locations across Columbus in well-lighted, relatively open spaces free from power lines and other significant obstructions. Data were normally obtained at 30-m intervals at elevations beginning at 15 to 45 m and ending at 300 to 600 m above ground during ascents.

"2) Temperatures near the surface were obtained during continuous automobile traverses across the metropolitan area. The "primary" automobile travelled along the same path as and concurrently with the helicopter. The other usually traveled at approximately right angles to the mean wind direction in the lowest 50 to 100 m; it also furnished measurements at special locations and served as a back-up for the primary automobile.

"The telethermometer mounted on the primary automobile was similar to the one used on the helicopter. That telethermometer used with the other automobile was manufactured by the Yellow Springs Instrument Company; it has a time constant of roughly 2 s and an absolute accuracy of 1.2°F, and was read manually to the nearest 0.5°F. On each vehicle the thermistor was housed in a radiation shield (similar to the one previously described) that was attached 1.1 m above and 0.2 m forward of the front bumper; sensor height was about 1.5 m above the ground. Ventilation was provided by the forward motion of the automobile; measurements were taken at speeds of 15 to 30 m/s and away from traffic congestion on freeways or major thoroughfares. Fans were attached to the radiation shield to furnish ventilation when vehicles were not in motion so that the instruments could be compared with each other, with the telethermometer on the helicopter, and with a standard mercury-in-glass thermometer. The instruments were compared in this manner before and after each experimental period and at other times when it was deemed necessary.

"3) Theodolite observations of winds to between 600 and 900 m above the surface were obtained at several locations across the metropolitan area. In September balloons were launched at upwind rural and near-downtown locations, and were tracked by a single theodolite. In March balloons were launched from upwind rural, near-downtown, and downwind rural sites, and were tracked by two theodolites. Three to five balloons per 2-h intervals were released at each site. Theodolite readings to the nearest 0.1°F of azimuth and elevation were obtained at 20-s intervals. Balloon ascent rates usually ranged between 100 and 140 m/min. The near-downtown site was in a relatively open section but necessitated the use of baselines only 120 to 190 m in length for the double-theodolite ascents; in the rural environs, baselines were normally in excess of 300 m.

"4) Measurements of surface ("skin") temperature were made with a Barnes radiation thermometer. Radiation from an emitting surface between the wavelengths of 9 and 13 μ was detected by a thermistor bolometer; in this band the atmosphere is nearly transparent to infrared radiation. Immediately prior to use, the instrument was calibrated with a standard mercury-in-glass thermometer over an agitated water surface at temperatures from 0°C to 30°C. The detector was mounted above a small hole in the belly of a fixed-wing aircraft. The aircraft was flown on a spoke-wheel pattern consisting of 22.5 degree arcs over the metropolitan area. The flight altitude was 600 m above ground in accordance with local Federal Aviation Agency (FAA) regulations. The aircraft was flown for 2 h prior to midnight and for 2 h prior to sunrise. Supplementary positioning and vectoring information was provided by the FAA radar operators. Finally, data were recorded on an analog chart; the observer on board the aircraft noted time-location data on this chart using information obtained from FAA radar personnel, the aircraft pilot, and visual observations.

"5) Measurements of turbulent wind fluctuations were obtained with bidirectional vanes located on masts 10 m above building roofs in the downtown area. Climet bivanes were, respectively, situated on masts above the roofs of 6- and 25-story buildings. The data were recorded on analog equipment. Special high speed runs of 15 min in duration were accomplished at 2-h intervals. Chart speed was 12 in/min during the special runs and 12 in/h at all other times. These data were not analyzed.

"6) One meteorological tracer experiment was conducted during the March series to obtain quantitative information on the height and rate of growth of the nocturnal urban boundary layer, on the relation between the thermal and pollution boundary layers, and on the urban heat plume. Sulphur hexafluoride (SF_6), an inert halide with an undetectable natural background, was released at a constant rate over a 1-h period. The dissemination was from a 1.5 m high source in the upwind residential area. Measurements of total dosage were made at preselected locations at near-ground level and on building roofs. Measurements of crosswind integrated concentration were obtained during helicopter traverses through the tracer plume at selected elevations at several downwind distances. The samples were collected in teflon bags and later analyzed by methods of gas chromatography.

"7) Grab samples of ambient air were obtained in 1-qt evacuated cylinders on several occasions during the September series by the crews of the primary automobile and the helicopter. Samples were analyzed later for carbon monoxide (CO) and methane (CH_4) content quantitatively by methods of gas chromatography. The underlying reason for this sampling was basically the same as for the meteorological tracer experiment.

"8) During the March series, tetroons were launched upwind of the urban area and tracked continuously until they were well downwind of the city by radar operated by the National Oceanic Atmospheric Administration (NOAA) personnel from Silver Spring, Maryland. Data concerning turbulent and mean properties of the airflow obtained from these tetroon trajectories were analyzed by these same investigators."

Data is in the form of strip charts in John Clarke's office at Research Triangle Park, North Carolina.

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Edmonton, Alberta

Edmonton is a city of about one-half million people located on the North Saskatchewan river. The surrounding topography is generally flat except for the steep and narrow river valley which runs through Edmonton in a southwest-northeast direction. The city is located on the Alberta plains well away from the Canadian Rockies.

A rather interesting study of the nocturnal urban boundary layer was done in Edmonton in November and December 1974.[25] The 3 wk field study took place in synoptic conditions normal for the season except that no significant snow cover was present. The observation systems consisted of two mobile minisondes, a helicopter, and two instrumented towers.

The minisondes are pilot balloons carrying aloft a microbead thermistor with a time constant of 1.5 s and an accuracy of 0.2°C. The balloon was tracked by the double theodolite method. The minisonde ascents were comparative; one sonde was always launched near the city center, while the other was launched at an upwind rural site. Launch times were either shortly before sunrise or shortly after sunset.

A helicopter instrumented with a Sign-X temperature unit was making conjunctive measurements. The temperature unit consisted of a shielded thermistor with a response time of 45 s and an accuracy of 0.2°C. The helicopter altitude was obtained from a pressure transducer to an accuracy of 5 m. Helicopter soundings extended along the line between the upwind minisonde sounding through the city center all the way to the downwind side of the city. These soundings give a good view of the urban effect upon the nocturnal boundary layer.

The two towers--one rural and one urban--were instrumented exactly alike for continuous measurement. In both cases temperatures were measured at 10, 47.5, and 91.5 m. The 10- and 91.5-m temperatures were taken by Rosemount platinum resistance thermometers in aspirated radiation shields. At both towers wind was measured at 91.5 m by standard Atmospheric Environment anemometers.

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[25]R. P. Angle and J. E. Torneby, 1975, "The Coordination of a Joint Air Pollution Field Study in Edmonton, Alberta," presented at the 1975 Annual Meeting of PNWIS-APCA, Vancouver, BC

Another study[26] between 1968 and 1971 involved the placement of seven thermographs around Edmonton. The thermographs were shielded and placed at 1.5 m above ground. Calibration was good, however, the shielding was inadequate during strong sunshine. Vertical temperature was measured on booms at 17 and 112 m on the Canadian National Tower in downtown Edmonton. Measurement was via shielded aspirated electrical resistance thermometers.

Regular Atmospheric Environment Service stations exist at the three Edmonton airports. One airport is located within Edmonton, one just north of the city, and the International airport is located 10 mi to the south. At all three airports all desired measurements except turbulent diffusion coefficients are taken hourly. This data is available on magnetic tape from the Atmospheric Environment Service, Toronto. Radiosonde observations are made approximately 50 km west of Edmonton where net radiation is also observed. The radiosonde is launched twice daily at the standard times.

A micrometeorological study of winds and temperatures within the North Saskatchewan river was recently done.[27]

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Fort Wayne, Indiana

Fort Wayne is surrounded by flat farm land. The city is about 11 km from north to south and 9.7 km from east to west. The population is about 180,000.

During the summer of 1964 and the winter of 1965 to 1966 an investigation of the air flow in and around Fort Wayne was carried out.[28] The investigation, which involved the diffusion of aerosols released from aerial line sources upwind of the urban area, was performed during 21 separate experimental periods. During these experimental periods, meteorological measurements were made at 10 surface locations in and around the city, from two towers, and from balloons and aircraft. The tests were conducted at night when the boundary layer was stable or neutral.

Meteorological data at the surface sites consisted of wind measurements at 9.1 m and temperature measurements at 1.5 m. Four of the surface stations

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[26]K. D. Hage, 1977, "Research in Urban Climatology at the University of Alberta," extract from Climatological Bulletin, 22:25-29, McGill University, Montreal, Canada

[27]R. D. Paterson and K. D. Hage, 1979, "Micrometeorological Study of an Urban Valley," Boundary Layer Meteorology, 17:175-186

[28]G. R. Hilst and N. E. Bowne, 1966, "A Study of the Diffusion of Aerosols Released from Aerial Line Sources Upwind of an Urban Complex," Final Report, Volume I under Contract DA-42-007-AMC-38R, US Army Dugway Proving Ground, Dugway, UT

were equipped with Meteorology Research, Incorporated, vector vanes (model 1053). The other six surface stations were equipped with Climet wind equipment modified to provide the horizontal wind components. All surface stations were equipped with Minco Thermohm sensing elements (No 315-10B) having a resistance of 100 Ω at 0°C. The thermohm elements were contained in Beckman and Whitley aspirated radiation shields (model N3270AA). Both the wind and temperature data were continuously recorded on strip charts during each experimental period.

Temperature and wind data were also obtained from two towers. The WANE television tower had wind and temperature sensors at 12.2, 30.5, 61, 91, and 213 m. A General Telephone relay tower had sensors at 15.2, 22.9, 30.5, 47.2, and 53 m. The temperature and wind sensors were the same as those used at the surface sites. Vector Vanes were located at 12.2, 61, and 213 m on the TV tower and at 15.2, 30.5, and 57 m on the relay tower. Climet wind equipment was located at 30.5 and 91 m on the TV tower and at 22.9 and 47.2 m on the relay tower. Temperature and Climet wind data were recorded on strip charts while the Vector Vane data was written on analog magnetic tape.

The Climet wind equipment used at the surface and tower sites had a threshold sensitivity of 0.75 mi/h with a range of 90 mi/h. The accuracy is 1 percent in speed and three degrees in direction.

Aircraft meteorological measurements of temperature and turbulence were carried out using a Meteorology Research Incorporated universal turbulence indicator and temperature probe. In addition, a Barnes Type A infrared thermometer having a range of -40°F to +145°F and a sensitivity of 1.5°F was used to monitor ground temperature. All data was recorded on strip charts.

Balloon measurements consisted of modified radiosondes to 5000 ft launched from field headquarters on Washington Boulevard, wiresondes (to 1500 ft) and pibals (to 3000 ft).

In addition to the meteorological observations, fluorescent tracer materials were released from aircraft upwind of the urban complex and monitored at a large number of surface sites. Two types of tracer materials were used. One contained a yellow pigment consisting of 1.32 X 10^{10} particles per gram with a mean mass diameter of 3.31μm. The other contained a green pigment with 1.45 X 10^{10} particles per gram and a mean mass diameter of 3.2μm. One release was made during 1964 using the green pigment having 1.62 X 10^{10} particles per gram and a 3.09μm mean mass diameter.

Three types of sampling equipment were used to determine tracer concentrations at the various surface locations. Gelman membrane filters were used at 25 sites. Ten such filter samples were taken sequentially at each site over 30-min intervals. An eleventh filter was run at each site continuously during the test period. Gelman paper tape air samplers were used at 10 locations to determine the arrival and departure times of the tracer materials. These samplers were programmed to step at 5-min intervals. In addition to the filter and paper tape samplers, rotorod samplers having a nominal sampling rate of 41.3 lpm at 2400 rpm were used.

Exact locations of surface sampling sites, aircraft flight trajectories and balloon launch sites are available.

Hamilton, Ontario

Hamilton, Ontario (43°N, 79°W) presents an extremely complex situation. Under given synoptic conditions there are three interacting sets of climatic controls, each operating on different space and time scales. These controls are the topography, the urban surface, and the proximity of Lake Ontario.

Hamilton is an industrial city with a population of approximately 300,000 covering an area of 111 km² at the western end of Lake Ontario. The city is sharply divided by the Niagara Escarpment into two levels whose altitudes differ by 100 m. The scarp face is indented with a number of deep valleys, especially the south-west/north-east oriented Dundas Valley to the west, and the north/south aligned valley of Redhill Creek to the east of the city.

The city readily lends itself to a division into five major land-use types. There is a sector of heavy industry concentrated along the southern shore of Hamilton harbour. The major steel plants are located here, together with a number of associated industries. The central business district of Hamilton is located towards the western end of the coastal plain. The remaining lower level of the city contains commercial and residential areas. The upper level of the city is primarily residential.

Air temperature data[29] were gathered by means of traverses conducted simultaneously by six automobiles, each equipped with an Assman psychrometer. During a 2-h period each automobile stopped at approximately 30 locations. At each location an observer took readings at a height of 1 m over a representative site well away from the car. During 1965 and 1966, 20 such surveys were conducted under different synoptic conditions.

Standard meteorological data were taken by the Meteorological Branch of the Department of Transport at the Royal Botanical Gardens, and the Hamilton Municipal Laboratories. Winds and temperatures were also measured at two levels on a 200-ft tower. The standard data is available on magnetic tape from the Atmospheric Environment Service.

Johannesburg, Republic of South Africa

Southern Africa's largest city lies astride a ridge at [illegible] to 6000 ft altitude. During the period of urban observations, 1970 to 1972, Johannesburg had a population of 1,432,634 (1970) with a metropolitan population of greater than 2,000,000. Johannesburg is located at 26°S and 28°E.

29T. R. Oke and F. G. Hannell, 1970, "The form of the Urban Heat Island in Hamilton, Canada, in Urban Climates," WMO Technical Notes 108:113-126

During the Johannesburg Urban Meteorology Study[30,31] measurements were made at two urban tower locations astride the Witwatersrand in addition to five regular temperature sites at which a helicopter descended from 1000 m to as near the ground as possible. These sites are representative of urban, suburban, and rural land use. For each helicopter ascent there are 90 to 120 discrete temperature values. Care was taken to reduce any helicopter effects on the temperature profile by descending/ascending in a spiral manner. The helicopter had a Rustrade model 2133 strip chart recorder with an accuracy of 2 percent over its total span of 40°C.

Wind and temperature data was taken at the 50, 100, 150, and 200 m levels on both towers. In addition, the synoptic rawinsonde balloon is launched twice daily at nearby Irene (40 km northeast).

A surface network of three stations for wind and temperature is separately archived from the helicopter and tower profile data. Finally an acoustic sounder was in operation at the University of the Witwatersrand.

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Las Vegas, Nevada

Urban meteorology data was collected as part of a special air quality study in the Las Vegas valley during winter 1975 to 1976, summer 1976, and summer 1977. Measurements of surface wind and temperature* were made at 14 locations. The surface observations were made at both rural and urban sites.

Pibals and tethered balloon temperature measurements were made on about 30 special occasions. The special occasions are about equally divided between the three observing periods mentioned above. The balloon observations were generally made at one site that was well away from the central city. In a limited number of cases, the pibal and tethered balloon were at different locations. Wind was derived either via the pibal or via a magnetic technique using the tethered balloon.

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[30] P. D. Tyson, W. J. F. DuToit, and R. F. Fuggle, 1972, "Temperature Structure Above Cities: Review and Preliminary Findings from the Johannesburg Urban Heat Island Project," Atmos Environ, 6:533-542

[31] R. G. Van Gogh and P. D. Tyson, 1977, "Aspects of Wintertime Mesoscale Temperature Structure over Johannesburg," Occasional Paper 17, Department of Geography and Environmental Studies, University of the Witwatersrand, Johannesburg, South Africa

*J. F. McElroy, 1982, personal communication

The balloon observations were made hourly from sunrise until the hour of ozone maximum. Since ozone maximum occurred between mid-morning to mid-afternoon, the duration of the data is highly variable. The balloons were launched downwind from Las Vegas.

Unfortunately most of the data resides on cassette tapes. An estimated 10 percent is available on magnetic tape, and it has been used for case studies.

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Louisville, Kentucky

Between July 2 and December 21, 1956, a surface and tower network was operating in Louisville, Kentucky.[32] The data consists of hour averages. The surface network consisted of five stations measuring windspeed, wind direction, relative humidity, dewpoint, and temperature. At three of these stations, the winds were measured atop 55 ft towers with Beckman and Whitley k-100A wind system transmitters. Two other tower wind measurements were done. One was at the 96 ft level on an open framework tower atop a building. An Instruments Corporation Anemograph Model R-329 wind system was mounted there. The other was a Bendix-Frieze aerovane at 524 ft mounted on a television tower. In addition, measurements were made at the Weather Bureau Airport Station.

Radiation measurements were made hourly on a pyranometer to the nearest 0.1 langley/minute. Temperature measurements were accurate to ±0.5°F while humidity was accurate to ±1 percent. The data is not archived.

Montreal, Quebec

Montreal has a population of slightly over one million with a metropolitan area population in excess of two million. It is located at a latitude of 46°N and a longitude of about 74°W. Meteorological measurements were carried out during 1969 and 1970 at three fixed surface sites, from helicopters, towers, and automobiles.[33] * Fixed site and helicopter observations were made on 80 days, usually during a 2-h period shortly after sunrise. On ten days, observations were also made in the early afternoon. Automobile traverses were carried out on only four or five days. Data was primarily collected during winter but some collection was done for all seasons.

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[32] F. Pooler Jr., 1963, "Airflow Over a City in Terrain of Moderate Relief," J Appl Meteorol, 2:446-456

[33] T. R. Oke and C. East, 1971, "The Urban Boundary Layer in Montreal," Boundary-Layer Meteorol, 1:411-437

*C. East, 1982, personal communication

Surface measurements of temperature, wind velocity, relative humidity, dewpoint, and cloud cover were conducted at Dorval International Airport about 14 km southwest of the downtown area. Temperature and wind velocity were also observed from towers located at Mount Royal (317 m above mean sea level) just west of the downtown area and at the Botanical Gardens (6 m and 60 m above the surface) located about 7 km north of the downtown area. Tower data was reported hourly.

Helicopter temperature soundings were carried out 12 times a day to a height of 900 m using a shielded thermistor having a reported accuracy of 0.2°C and a response time of 0.5 s. Concentration profiles of SO_2 were also obtained by the helicopter.

Three automobiles were equipped to record temperatures at a height of 1.5 m using aspirated shielded thermistors. These thermistors are reported to have all the same performance characteristics as the one used on the helicopter. Additional spot temperatures were obtained by three other automobile teams using Assmann aspirated psychrometers.

Data for this project are available in tabular form for wind measurements at the three fixed locations and computer listings for the helicopter soundings. Significant changes in land use have probably occurred since the 1969 to 1970 observational period. It should be possible, however, to determine land use categorization at the time of the experiment.

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New York City, New York

The New York Air Pollution Project (NYAPP) ran from July 1964 through 1969.[34 35 36] A preliminary observation period covered the time span from July 1964 through April 1965, while 12 test periods and 2 interim periods were held between September 1965 and December 1966. More details on the twelve test periods can be seen in table 2.

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[34] B. Davidson, 1967, "A Summary of the New York Urban Air Pollution Dynamics Research Program," Journal of the Air Pollution Control Association, 17(3):154-158

[35] R. D. Bornstein, 1968, "Observations of the Urban Heat Island Effect in New York City," J Appl Meteorol, 7:575-582

[36] R. D. Bornstein et al, 1977, New York City Air Pollution Project of 1964-1969, Volume I, Description of Data, EPA-600/4-77-035, Environmental Protection Agency, Washington, DC

TABLE 2
SUMMARY OF THE NEW YORK CITY AIR POLLUTION PROJECT DATA SET.

TEST PERIOD CODE	(DATE)	MESOSCALE WIND MAPS NO.	TYPE	HELICOPTER TEMP. SOUNDINGS NO.	TYPE	PIBAL WIND OBS. NO.	TYPE	MESOSCALE SO_2 MAPS NO.	TYPE	HELICOPTER SO_2 SOUNDINGS NO.	TYPE
PT-1	(7/7/64-4/30/65)	NONE		150	SIGN-X	853	S	NONE		49	SIGN-X
				7	NYU	74	D			7	NYU
				23	SJ25	136	DD				
T-1	(9/19/65-9/24/65)	NONE		15	NYU	43	S	NONE		15	NYU
T-2	(10/14/65-10/16/65)	36	NYU	53	SIGN-X	63	S	61	NYU	45	SIGN-X
				3	NYU					25	NYU
I-2/3	(10/18/65)	NONE		3	SIGN-X	NONE		NONE		NONE	
T-3	(cancelled)	NONE		NONE		NONE		NONE		NONE	
T-4	(12/7/65-12/12/65)	NONE		61	SIGN-X	126	S	61	NYU	36	SIGN-X
				15	SJ25						
T-5	(2/2/66-2/5/66)	96	NYU	33	SIGN-X	116	S	113	NYU	38	NYU
				38	NYU						
*T-6	(3/8/66-3/12/66)	120	SJSU	5	SIGN-X	202	S	60	SJSU	5	SIGN-X
				98	NYU					98	NYU
I-6/7	(3/22/66-3/23/66)	NONE		7	SIGN-X	NONE		NONE		NONE	
				2	SJ25						
T-7	(5/2/66-5/7/66)	72	NYU	59	NYU	240	S	106	NYU	59	NYU
				15	SJ25					49	SIGN-X
I-7/8	(5/24/66-9/9/66)	NONE		134	SIGN-X	2	S	NONE		NONE	
				29	SJ25						
T-8	(10/3/66-10/6/66)	72	NYU	5	SIGN-X	83	S	62	NYU	46	NYU
				46	NYU					5	SIGN-X
I-8/9	(10/25/66-10/27/66)	NONE		17	SJ25	18	S	NONE		NONE	
T-9	(10/31/66-11/1/66)	24	NYU	17	NYU	86	S	36	NYU	17	NYU
*T-10	(11/15/66-11/17/66)	108	SJSU	19	NYU	170	S	50	SJSU	19	NYU
				16	SIGN-X					16	SIGN-X
				37	SJ10					37	SJ10
T-11	(11/23/66-11/25/66)	48	NYU	NONE		NONE		72	NYU	NONE	
*T-12	(12/5/66-12/8/66)	72	SJSU	1	SJ10	209	S	36	SJSU	7	SJ10
				42	SIGN-X					33	SIGN-X

* Primary Test Period.

NYU - Soundings from original data averaged over 50 m intervals.
SJSU - Soundings produced from original data extracted at 10 or 25 m intervals.
SJ 25 - Soundings from data extracted at 25 m intervals.
SJ 10 - Soundings from data extracted at 10 m intervals.
Sign-X - Soundings produced from 25 m data.
S - Single pibal launch.
D - Double pibal launch.
DD - Double double pibal launch.

New York City is one of the world's largest metropolitan areas with a population of about 17,000,000 people over an area of about [illegible] mi^2. The urban effect in New York is complicated by the hills to the west and north in New Jersey and by the ocean to the east and south. New York is primarily located on several islands so that its urban climate is strongly influenced by the ocean. In addition, the land use patterns in and around New York are quite complicated with several central business districts. While use of NYAPP data is not desirable in a preliminary application for inferring urban meteorological conditions, it may offer a good means for incorporating more complicated effects such as the sea breeze in later work.

The NYAPP was conducted primarily by New York University (NYU). Later, the data was processed and is presently archived at the National Technical Information Service (NTIS) in Springfield, Virginia. The experiment incorporates extensive seasonal variation because of its duration and diurnal variation by virtue of the various experimental times. Very extensive data networks were in operation during the experiment.

An extensive anemometer network of 97 sites was in operation. Fourteen sites were at airports, four at Air Force or Navy bases, ten at Coast Guard bases, fifteen at utilities, twenty-nine at public agencies and institutions, and eleven at sites administered by NYU. The wind data consists of hourly averages except the airport, military, and Coast Guard data are standard hourly observations. The locations of the anemometer network are included in figure 2 and table 3.

Temperature, relative humidity or dewpoint, and cloud cover surface observations are available only at the New York area stations whose data are archived at the National Climatic Center (NCC). This data is available hourly for airport, military, and Coast Guard stations.

The upper air network for NYAPP was very extensive. The various measuring systems included pibals, helicopter soundings, fixed wing aircraft, and the National Weather Service (NWS) rawinsonde at John F. Kennedy (JFK) International Airport. The pibal launch sites are shown in figure 3. During the NYAPP, a total of 2418 pibal wind observations were made. The location of helicopter sounding sites is shown in figure 4; a total of 960 were made. Generally, the helicopter flight path was dependent upon a mission objective. Twelve soundings were made during each flight, and three flights were made per day; at sunrise, midday, and sundown.

A Brantly B2 helicopter and a Piper PA-12 light plane were used for soundings. On missions requiring a larger helicopter, a Bell 47J helicopter was used. On flights during 1964 and 1965, temperature and wet-bulb depression were measured. In 1966 wet-bulb observations were generally not taken.

The temperature sensor consisted of a semiconductor head. The output of the head was a linear function of temperature and had a time constant of approximately 0.2 s. The overall temperature measuring system consisting of sensor, amplifier, and recorder, had a relative accuracy of 0.2°C and an absolute accuracy of 0.5°C. The wet-bulb depression sensor consisted of a double thermocouple. Each thermocouple had 30 thermofunctions, and 1 thermocouple was fed with distilled water. The time constant of the wet-bulb depression sensor was 0.1 to 0.2 s, and its accuracy was 0.2°C.

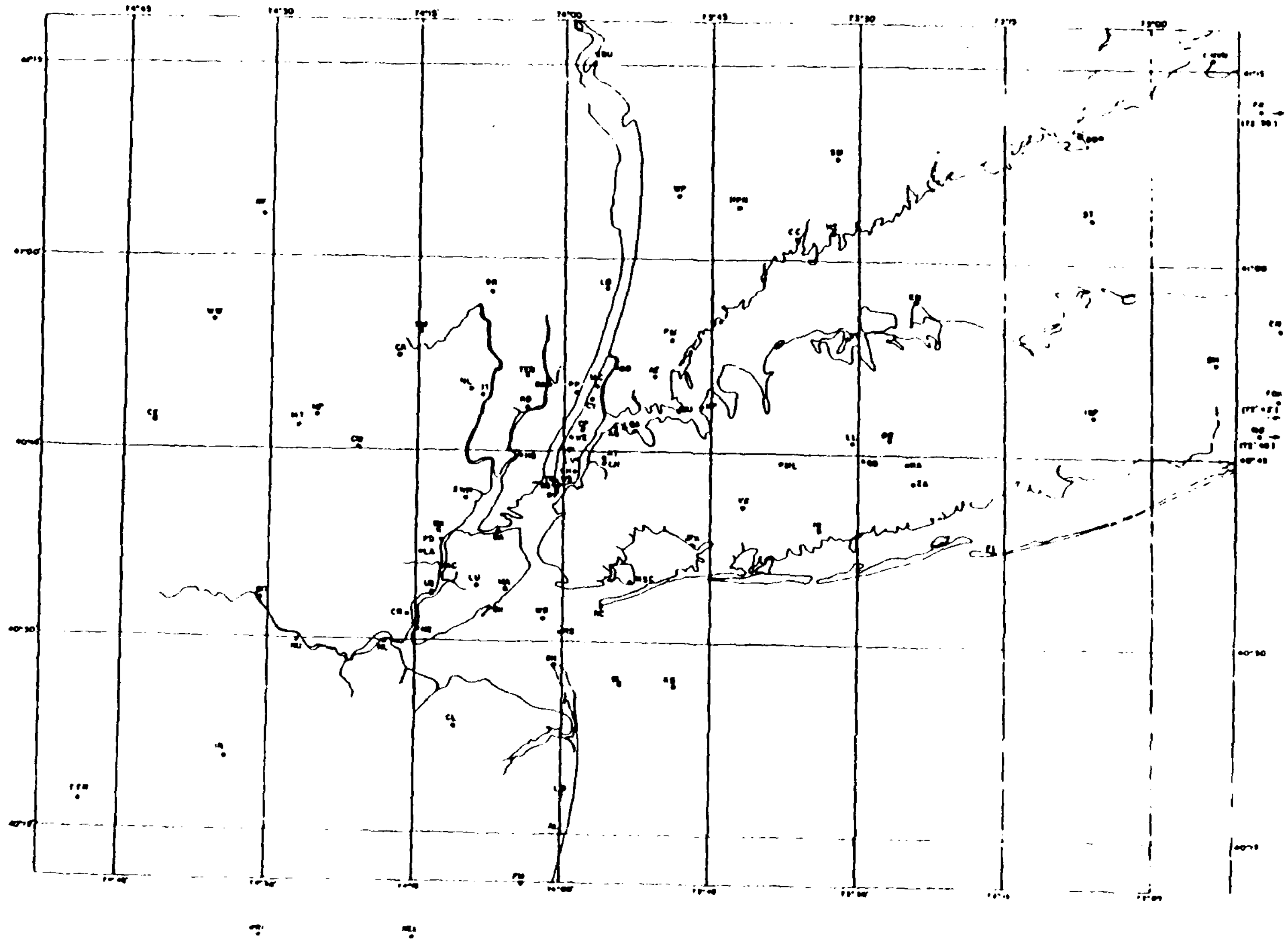


Figure 2. Location of surface anemometer sites by abbreviations used in Table 3.

TABLE ?

ALPHABETICAL LISTING OF SURFACE ANEMOMETER SIT[illegible] APP[illegible]ARI[illegible] [illegible] [illegible]

CODE LETTERS	STATION NAME	LAT. (D M S)	LONG. (D M S)	DATA TYPE	OBSTRUCTED ARC	PROBLEMS
AE	Albert Einstein Sch.	40 51 30	73 50 45	A	WNW	
AG	Astoria Generator	40 47 06	73 54 45	[illegible]		[illegible]
AL	Allenhurst	40 15	74 [illegible] 00	A		
AS	Ambrose Light Ship	40 27 20	73 [illegible] 00	[illegible]		
BA	Bayonne	40 41	74 07			
BB	Bliss Bldg., NYU	40 51 40	73 54 45	[illegible]	[illegible]	
BDR	Bridgeport Airport	41 10	73 07	[illegible]		
BG	Bergen Generator	40 50 25	74 01 43	[illegible]	NE	[illegible]
BO	Bound Brook	40 33 30	74 30 30			[illegible]
BR	Bayway Refinery	40 38 40	74 12 30	A	[illegible]	[illegible]
BT	Yonkers	40 58	73 53	[illegible]		[illegible]
BU	Buchanan	41 16 10	73 57 00	A		[illegible]
CA	Caldwell Airport	40 52 35	74 16 55	C		
CC	Cos Cob	41 01 48	73 35 54	A		[illegible]
CE	Chester	40 48	74 42	A		[illegible], F
CH	Christadora House	40 43 30	73 58 50	B		[illegible]
CL	Crawford Hill	40 23	74 11	B		F
CN	Grumman Aircraft	40 55	72 47	W		
CP	Central Park	40 46 45	73 58 10	O	NNE	[illegible]
CR	Perth Amboy	40 32 05	74 15 48	A		
CW	Commonwelth Water	40 15	74 21	[illegible]		
CY	City College of N.Y.	40 49 15	73 57	A		P
DA	Con. Edison	40 38 40	74 06 40	B		
EN	Eatons Neck	40 52 02	73 23 02	WO		
ER	Execution Rocks	40 52 40	73 44 00	WO		
EWR	Newark Airport	40 31 00	74 09 30	W		
FH	Fort Hamilton	40 36	74 01	[illegible]		
FI	Fire Island	40 37 05	73 15 06	WO		
FK	Falkners Island	41 12 07	72 39 02	WO		
FM	Fort Monmouth	40 11	74 04	B	F	
FOK	Suffolk	40 50	72 40	W		
FV	Fairview	40 49	74 00	[illegible]		[illegible], F
GB	Bathpage	40 44	73 29	WO		
GK	Great Kills	40 32 45	74 07 26	P		
GR	Glenrock School	40 57 28	74 07 29	B		
HE	Stamford	41 02 26	73 23 39	[illegible]	[illegible]	[illegible]
HG	Hudson Generator	40 44 41	74 04 24	B	[illegible] NW	
HI	Merrick	40 38 59	73 33 45	[illegible]		
HL	Hoffman Laroche	40 49 48	74 09 30	A		[illegible]
HP	Pier 68 Heliport	40 45 15	74 00 30	B	NE [illegible]	[illegible]
HPN	White Plains Airport	41 04	73 44	W		
HR	West Hempstead	40 42	73 39	O	WNW	
HVN	New Haven Airport	41 16	72 58	W		
IR	Plainsboro	40 20 47	74 34 20	B		
IS	Westwood	40 59	74 00 54	C	NNE	
ISP	Islip Airport	40 43	73 06	W		
IT	Nutley	40 49 10	74 09 10	[illegible]		
JFK	JFK Intn'l. Airport	40 38 05	73 46 45	[illegible]		
KP	Kings Point Academy	40 48 50	74 45 55	P		
LA	Linden Airport	40 37	74 14	[illegible]		[illegible]
LB	Long Branch	40 18	74 00	[illegible]		
LGA	La Guardia Airport	40 46 50	73 52 35	W		
LGA	La Guardia Airport	40 46 50	73 52 35	[illegible]		
LH	Laural Hills	40 44 12	73 55 48	[illegible]	[illegible]	[illegible]
LL	Long Is. Lighting	40 45 48	73 30 48	B		[illegible]
LO	Lamont Tower	40 57 30	73 55 25	A		[illegible]
LU	Latouratte	40 34 30	74 03 55	P		
LV	Lehigh Valley	40 44 30	73 58 20	B	[illegible] NNE	[illegible]
MA	Fort Miller	40 34 08	74 24 08	B		
MC	Medical Center	40 50 25	73 56 30	P		
ML	Mineola	40 44 10	73 30 00	B		[illegible]
MO	Moriches	04 47 02	72 45 00	WO		
MP	Morristown Airport	40 47 50	74 25 05	[illegible]		
MT	Morristown	40 46 45	74 27 00	A	N	[illegible]
NEL	Lakehurst	40 10	74 [illegible]	W		

TABLE 3 (CONTINUED)

CODE LETTERS	STATION NAME	LAT. (D	M	S)	LONG. (D	M	S)	DATA TYPE	OBSTRUCTED ARC	PROBLEMS
NL	Nation Lead	40	29	50	74	18	35	A		
NR	New Rochelle	40	54		73	47		[illegible]		
NS	Totenville	40	32		74	14		A		[illegible]
NSC	Floyd Bennett	40	35		73	53		W		
OB	Oyster Bay	40	46	15	73	28	40	B	6	
OC	Oceanside	40	37	10	73	38	21	[illegible]		D
PD	Phelps Dodge	40	38	05	74	12	10	B		S
PH	Pelham Manor	40	53	55	73	49	00	P		
PP	Palisades Park	40	49	45	73	53	30	P		
PA	Republic Aviation	40	44		73	25		W		D
RB	NYU Research No. 4	40	48	35	74	03	45	B		
RC	Rockaway	40	33	02	73	56	02	WQ		D
RP	Roselle Park	40	39		74	16		[illegible]		S
RU	Rutgers Univ.	40	30		74	27		B		L
SB	Sheraton Bldg.	40	42	15	74	01	00	[illegible]		
SH	Sandy Hook	40	28	01	74	01	00	WQ		
SM	Stamford	41	08		73	32		O		
ST	Stratford Shoals	40	03	04	73	06	01	WQ		
SU	Maritime College	40	48	20	73	47	42	B		D
TB	NY Telephone Co.	40	42	50	74	00	45	B		
TEB	Teterboro Airport	40	46		74	03	55	W		
TW	Totawe Wayne Airport	40	54	35	74	14	39	O		
US	U.S. Metals	40	35	55	74	13	15	B		L
VS	Memorial School	40	40	35	73	41	50			L
WE	West End	40	46	05	73	59	10	B	[illegible]	
WF	Whitehall Ferry	40	42		74	00	45	B	NONE	
WP	Westchester	41	04	45	73	48	20	B		D
WRI	McGuire	40	00	40	74	36	40	W		
WS	Wall Street	40	42	15	74	00	30	B		
WW	West Wharton	40	55		74	36		A		S, D
YC	Yatch Club	40	54	10	73	30	45	B		
ZA	Zahn's Airport	40	42		73	24		W		

NOTES:

I. TYPE OF DATA

A - TWO ROLL BENDIX
B - ONE ROLL BENDIX
O - VISUALLY OBSERVED
P - FROM SECOND LEVEL OF PIBAL
Q - QUADRUPLE, TRIPLE, OR DOUBLE REGISTER
W - WBAN 10 OR SERVICE A
WQ - COAST GUARD CIRCUIT (QUADRUPLE REGISTER)
U - UNKNOWN

II. FOOTNOTES

1. IF TWO DIRECTIONS GIVEN, FIRST IS BEGINNING OF OBSTRUCTED ARC AND LAST IS [illegible], MOVING IN A CLOCKWISE SENSE.
2. WIND SPEED CONVERTED FROM BEAUFORT.
3. IF WIND RECORDER INOPERATIVE, PIBAL WINDS SOMETIMES USED.
4. WIND SPEEDS REPORTED EITHER AS 2.5 OR 7.5 MPH; DATA NOT USED.
5. USED ONLY WHEN RECORDER WAS INOPERATIVE.
6. ROOF AERODYNAMIC EFFECT.
7. ALL QUADRANTS.
8. 287 m ABOVE GROUND LEVEL.

III. PROBLEMS

D - ORIENTATION PROBLEMS
F - TOO FAST
L - LOCAL EFFECTS
S - TOO SLOW

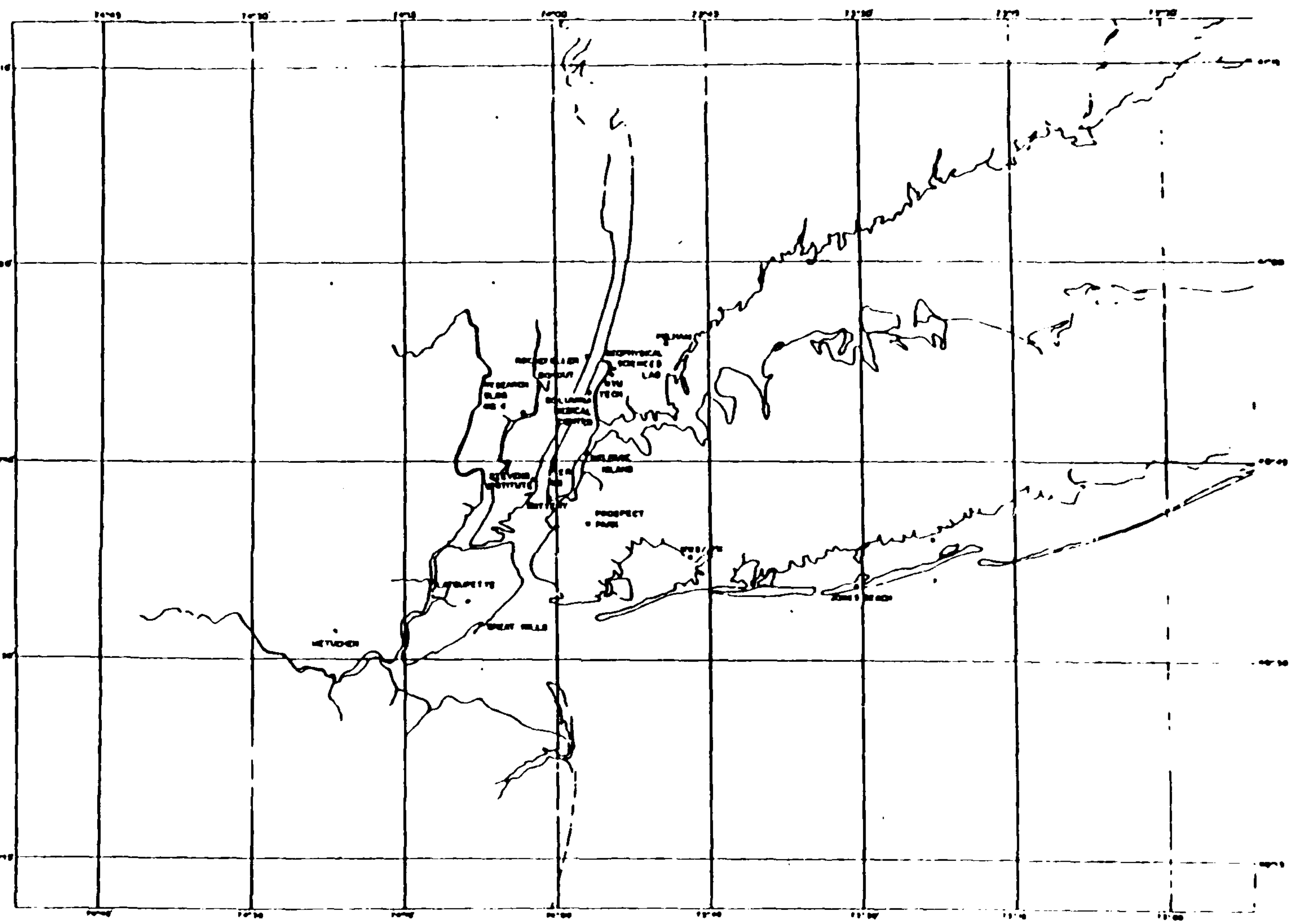
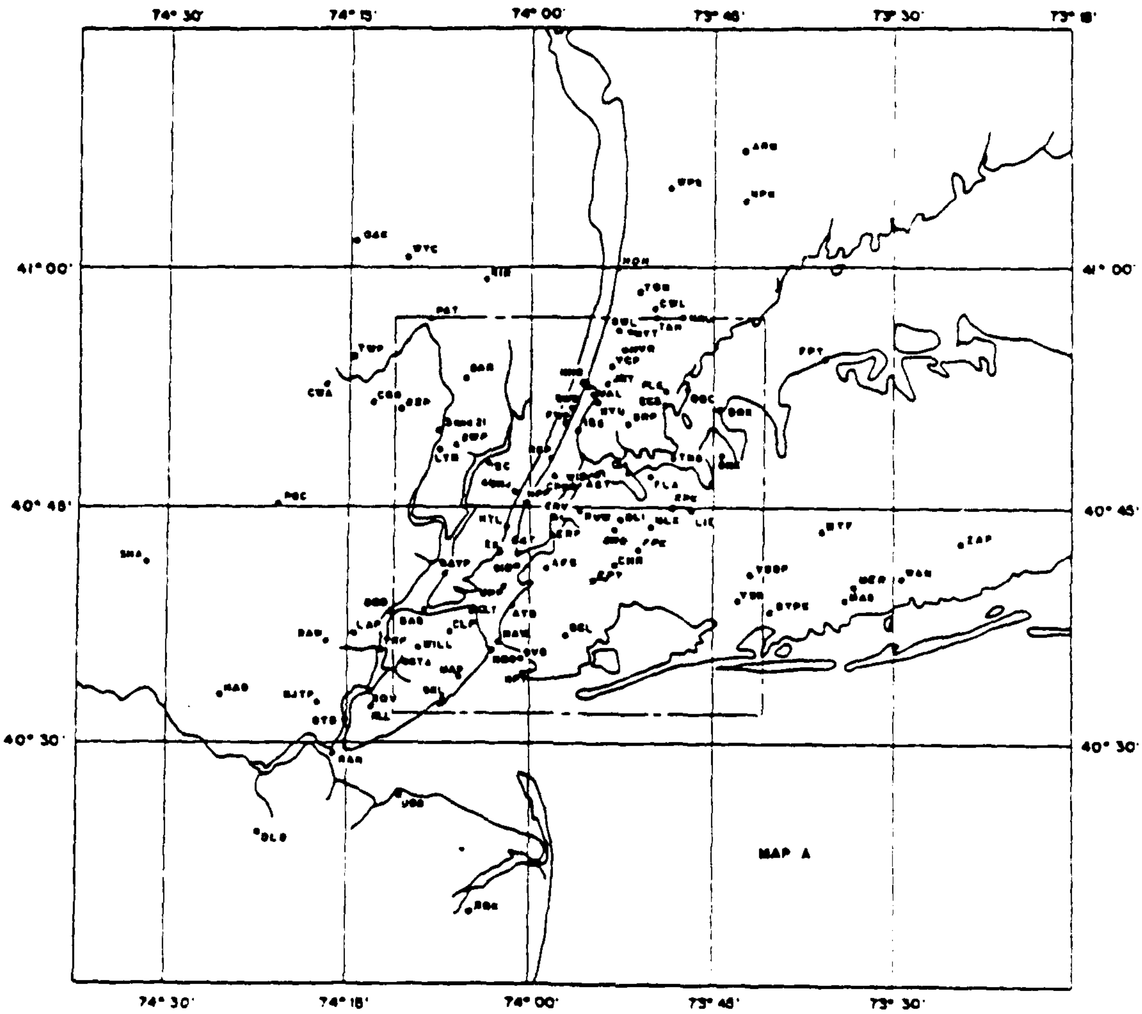
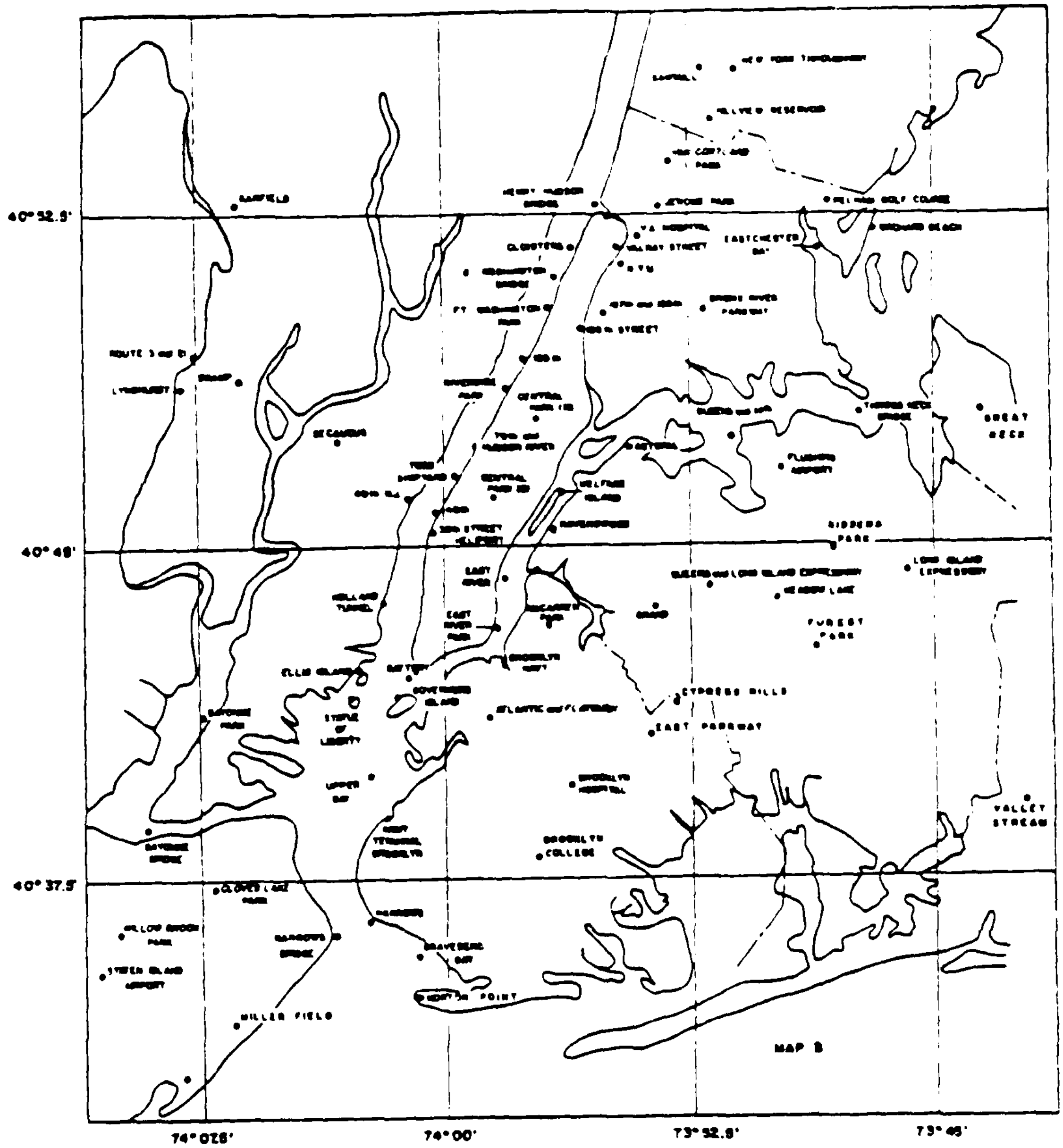


Figure 3. Location of pibal launch sites and NWS radiosonde site at JFK Airport.



(a)

Figure 4. Location of helicopter sounding sites.



(b)

Figure 4. (cont)

During the NYAPP, upper level wind data in the lowest kilometer of the atmosphere were obtained by the following methods: (1) a single theodolite tracking a single free-rising pilot balloon; (2) two theodolites tracking a single free-rising pilot balloon; (3) four theodolites tracking two free-rising pilot balloons; and (4) radar-tracked radiosonde launches at the US Weather Service site at JFK.

When four theodolites were used in an experiment, two of them were used to track each balloon. The two balloons were released from sites separated by about 1 mi and were tracked so that simultaneous readings were taken of each balloon by its two tracking theodolites. Results were used to estimate the time rate of change of the correlation coefficients obtained from the two velocity data sets.

The above pibal and rawinsonde data have been analyzed at San Jose State University (SJSU) by the following series of computer programs: (1) DATA CHK, which checks punched cards containing the original pibal and JFK observations for various key-punching and filing errors; (2) DATA, which transfers the original observations from the cards to a "BCD" formatted, unblocked, 7-track, 800 bpi computer input data tape and then prints the data; (3) DUMP, which lists any part of the input data tape; (4) EDIT, which can correct any errors found in the input data; (5) WIND, which computes and prints wind velocities for particular pibal runs using the data on the input data tape; (6) WIND2, which computes wind velocities from the input data tape for particular runs and then puts the output onto a new "BCD" formatted, unblocked, 7-track, 800 bpi computer tape; and (7) EPATAP, which reads the new tape generated by WIND2 and then lists the wind velocities for particular pibal runs.

The tape generated by the WIND2 computer program, and the EPATAP program necessary to read that tape to list the velocities from particular pibal runs are available at NTIS.

A constant rate of ascent of 150 m $\cdot$min^{-1} was assumed to obtain the height of the balloon at any given moment above the local ground level. Most of the theodolite azimuth and elevation readings were taken at 15-s intervals, although on occasion 30- or 60-s intervals were used. The 15-s interval yielded computed velocities at 37.5 m intervals, except in the case of missing levels, while a knowledge of the height of the launch site above mean sea level allowed for the data to be listed at heights above mean sea level.

Surface Wind Data

The original surface wind data rolls are generally not available, except for those from several of the sites operated by NYU. The available data rolls are currently at SJSU, as are the tabulated hourly averaged windspeed and wind direction data for many of the stations.

Pibal Wind Data

The original data sheets from all of the pibal launches are at SJSU. The data set includes single pibal launches (designated as "S"), double pibal launches (designated as "D"), and double-double pibal runs (designated as "DD").

Computer programs required to correct errors in the input data and to compute wind velocities are available at SJSU, as well as all of the corrected observations on a computer tape. The computed velocities from the three primary test periods are also on computer tape at the NTIS, along with the computer program (deck and listing) required to read the winds from the tape.

Helicopter Soundings

The original helicopter strip charts containing the SO_2 and temperature soundings are at SJSU. In addition, some of the strip charts obtained before the first test period contain additional soundings of wet-bulb temperature.

Synoptic Conditions for NYAPP Test Periods are as follows:

Test 1

September 19, 1965: An anticyclone dominated the east coast south of New York City (NYC) with a quasi-stationary front through the center of New York State (NYS) and Connecticut. The front moved (east to west) through NYC between 1800 and 2100Z, and the high associated with the new air mass was centered 400 mi east of NYC.

September 20, 1965: The front that passed through NYC on September 19 washed out in central Pennsylvania by 1800Z, resulting in a large high forming over the entire east coast and western Atlantic.

September 21, 1965: No change.

September 22, 1965: No change on east coast, but after 0000Z a cold front moved into the Ohio Valley.

September 23, 1965: The front slowed in the Ohio Valley, but as the high on the east coast weakened, the front began to move eastward with many waves.

September 24, 1965: The front entered eastern NYS by 0600Z but remained quasi-stationary with waving. It passed NYC at 0300Z, moving from west to east.

Test 2

October 13, 1965: An anticyclone moved from West Virginia to Delaware following a front located in the western Atlantic.

October 14, 1965: The high moved northeast but high pressure still dominated the entire east coast.

October 15, 1965: A ridge still existed over the east coast but by the end of the day a cold front moved into upper NYS.

October 16, 1965: The front passed through NYC at about 0600Z, followed by a high from Ontario.

October 17, 1965: The high first moved northeast and then moved down the Hudson River to a position over NYC at 2100Z.

October 18, 1965: The high remained stationary over NYC.

Test 3

Cancelled.

Test 4

December 7, 1965: A high was centered over the midwest with ridging into the northeast. The high later moved southeast.

December 8, 1965: The high moved into the southeast still ridging into the northeast. By 1800Z a front moved into upper NYS, and by 2100Z there was a frontolysis with a "peanut" low centered over Syracuse and Dover Air Force Base.

December 9, 1965: The ridge was reestablished by 0600Z and the high became quasi-stationary over the southeast.

December 10, 1965: A cold front entered upper NYS at 0900Z. The front passed NYC at 1200Z and by 1800Z the ridge formed a high centered in Ontario.

December 11, 1963: The surface ridge line moved into northwestern New England, and there was a warm front through Washington, DC.

December 12, 1965: The Canadian high intensified, increasing the ridging over the the east coast.

Test 5

February 2, 1966: A trough formed over the east coast between a low near Greenland and another low (with a frontal system) over Virginia.

February 3, 1966: Weak ridging from Philadelphia to Oklahoma.

February 4, 1966: A front entered upper NYS at 1500Z with a wave centered over southeastern Ontario. Frontolysis occurred at 2100Z.

February 5, 1966: A high centered over the Mississippi Valley dominated the entire eastern part of the country.

Test 6

March 8, 1966: A long wave trough was over the northeast with jets through the Ohio Valley and off the coast at Martha's Vineyard. At the surface a dynamic high dominated the east.

March 9, 1966: The long wave trough weakened and the jet moved northward into NYS. The highest speeds moved into Maine and a short wave ridge moved into the southwestern part of the Ohio Valley. The surface high moved northeast across the Ohio Valley into NYS. By 1200Z it began to move south.

March 10, 1966: The long wave ridge aloft was building over the western Ohio Valley. The jet maximum was accompanying a short wave ridge and was losing strength. The surface high became stationary over Norfolk, Virginia and began changing its thermal structure. By 2100Z a cold front had just passed Watertown, New York (moving south) and the high was breaking down.

March 11, 1966: A second jet maximum was over Quebec in association with a well-developed short wave trough and a closed low at 500 mbar over Montreal. The front moved through NYC at 1200Z. Following the front there was ridging from a dynamic high over Quebec. The ridge was bridging the front in the NYC area during the afternoon.

March 12, 1966: The upper level system moved eastward across the maritime provinces and a weak short wave ridge developed in association with the convergence zone of the jet maximum. The long wave pattern remained unchanged. By 0300Z the surface front moved southward to Washington, DC, and the high moved south-southeast with its center remaining in Quebec.

Test 7

May 3, 1966: A high was centered over the Missouri Valley with ridging into the northeast. There was frontogenesis over Maine, and a cold front moved rapidly into NYC.

May 4, 1966: The front moved into the NYC area by 0000Z and a post frontal high in Maine moved southeast through the Washington, DC area.

May 5, 1966: The high moved off the coast, and a second front was over Maine.

May 6, 1966: The front moved through NYC between 0600 and 1200Z. At 1200Z a short wave formed over Cleveland, and a wave moved through NYC after 1800Z.

May 7, 1966: A post frontal trough remained over the northeast.

Test 8

October 4, 1966: A stationary high existed in the Atlantic off of NYC and a cold front moved through the Ohio Valley into NYS by 0100Z.

October 5, 1966: The front passed NYC between 0600 and 1200Z, and the "triple point" also went through. A post frontal high was centered over the Missouri Valley.

October 6, 1966: The high moved northeastward into the Ohio Valley.

Test 9

November 1, 1966: A front with waves moved through the middle of NYC and then remained stationary.

November 2, 1966: A major wave developed over Georgia and moved northward along the front into Pennsylvania.

Test 10

November 15, 1966: At 0000Z the jet was through the Ohio Valley and off of the coast at Cape Hatteras. The axis of the long wave trough was through an area northeast and east of NYC. By 1200Z the jet moved to a position north of the city, and there was a jet maximum over northwest Ontario. At the surface at 0600Z, a dynamic high was centered in northwest Ontario with ridging into the Ohio Valley.

November 16, 1966: The flow was becoming more zonal with the jet split into two cores. The primary core was over southern Quebec, while the secondary core was over the southern Ohio Valley. At 0000Z the surface ridge was in NYS, while six hours later the high was centered over Alabama. By 1800Z the flow at NYC was southwest with a warm front near Buffalo.

November 17, 1966: The two jet cores merged and came off of the east coast at Washington, DC. A strong maximum was developed over Wisconsin. At 0000Z the surface front extended from Watertown, NYS, to Providence, RI. It then moved northward and became quasi-stationary in northern New England, with southwesterly flow remaining over NYC.

Test 11

November 23, 1966: A high centered over Washington DC dominated the entire east cost.

November 24, 1966: The high moved southward into Georgia.

November 25, 1966: *Weakening of the ridge in the northeast* allowed some quasi-stationary frontal activity in the northwestern part of New England.

Test 12

December 6, 1966: At 0000Z a dynamic high at 850 mbar over Charlestown, South Carolina, dominated the entire east coast. It was beginning to change its structure to a warm core high. The surface pattern was generally the same as that at 850 mbar.

December 7, 1966: The high at 850 mbar was a stationary warm core high centered at 30N and 75W. The surface pattern was generally the same as that at 850 mbar.

December 8, 1966: By 0000Z a front at 850 mbar was pushing into the Ohio Valley, increasing the windspeed over NYC up to 30 kn (from the west). By 0600Z the surface high was off of the coast, and there was strong southwesterly flow through the entire east coast.

St. Louis--Regional Air Pollution Study

The RAPS was a very extensive observation program conducted by the Environmental Protection Agency (EPA) for the St. Louis metropolitan area.[37] RAPS was organized to study air quality on the scale of an Air Quality Control Region. Besides making an inventory on emissions and air quality monitoring, many meteorological data were collected. This data is particularly relevant to use in an urban meteorology data base because of the density and duration of the data collection.

The Regional Air Monitoring System (RAMS) consisted of 25 meteorological towers. Seventeen towers were 30 m high, and 8 were 10 m high. At every RAMS site, windspeed and wind direction were measured at 10 or 30 m, temperatures at 5 m, and dewpoint at 2 m. On the 30-m towers, the temperature difference between 5 and 30 m was measured. Six towers, three 10 m and three 30 m, had radiation measurements. Windspeed and wind direction were measured, respectively, by an MRI 1022 S and D with accuracies of ±0.07 m/s and ±0.5 percent. Temperature and temperature gradient were measured respectively by an MRI 840-1 and a MRI 840-2 with respective accuracies of ±0.05°C and ±0.1°C. Dewpoint was measured with a Cambridge 880 to an accuracy of ±1°C. Solar radiation was measured by either an Eppley Pyranometer, Pyrheliometer, or Pyrgeometer to an accuracy of ±1 percent. RAMS data consists of 1-min averages based on 120 1/2-s readings.

The upper air station network (UASN) consisted of four stations; 141, 142, 143, and 144. Data were collected hourly for the period of August 1974 until May 1977. At each upper air station, cloud cover (visual), surface temperature, dewpoint temperature (sling psychrometer), surface windspeed and wind direction were taken. (Stations 141 and 142: Taylor Scientific Windscope model 3120, Stations 143 and 144: Dryer hand-held wind meter). Wind direction and windspeed aloft were taken by either a 10 g or 30 g pibal tracked by a single Warren-Knight theodolite or by a radiosonde; either VIZ 403 MHZ model 1395 tracked by a single Warren-Knight theodolite, or the model 1392 by a GMD-1A Rawin Set. The model 1395 RW used a Leeds and Northrup model 63-100, Leeds and Northrup model 211 CP, or Beukers Model 403 receiver; the model 1392 RW used a Bendix model TMQ-5GMD receiver. Temperature, relative humidity and barometric pressure were also measured.

At each upper air station, radiosondes were launched every 6 h (2200, 0400, 1000 and 1600 LST) while pibals were launched hourly between radiosonde observations. The balloons were tracked to 700 mbar with readings taken every 30 s or at significant levels for about 20 min.

A subsurface heat flux study was conducted from September 1975 through January 1978. The measurements are summarized in table 4. Measurements and instruments used were:

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[37] J. A. Strothmann and F. A. Schiermeier, 1979, Documentation of the Regional Air Pollution Study (RAPS) and Related Investigations in the St. Louis Air Quality Control Region, EPA-600/4-79-076, Environmental Protection Agency, Washington, DC

TABLE 4

SUBSURFACE HEAT FLUX STUDY EQUIPMENT PLACEMENT.

Sensor/ Instrument	Height	Concrete Area	Black Paint Concrete Area	Grassy Area	Station Shelter
Net Pyrradiometer	1.5 m AS	X	X	X	
Shielded Thermistor	4.0 m AS			X	
Shielded Thermistor	1.0 m AS	X	X	X	
Surface Thermistor	SURFACE	X	X	X	
Subsurface Thermistor	1.0 cm BS	X	X	X	
Subsurface Thermistor	3.0 cm BS	X	X	X	
Subsurface Thermistor	5.0 cm BS	X	X	X	
Subsurface Thermistor	7.0 cm BS	X	X		
Subsurface Thermistor	10.0 cm BS	X	X	X	
Subsurface Thermistor	15.0 cm BS			X	
Subsurface Thermistor	18.0 cm BS	X	X		
Subsurface Thermistor	20.0 cm BS			X	
Subsurface Thermistor	22.0 cm BS	X	X		
Subsurface Thermistor	30.0 cm BS	X		X	
Subsurface Thermistor	40.0 cm BS	X			
Subsurface Thermistor	50.0 cm BS	X		X	
Wind System	4.0 m AS			X	
Hygrothermograph	1.0 m AS			X	
Rain Gauge	0.5 m AS	X			
Hygrometer	1.0 m AS			X	
Microbarograph	2.0 m AS				X

AS = above surface BS = below surface

Subsurface temperature (Yellow Springs Instrument Co, model 401), surface temperature (Yellow Springs Instrument Co, model 408), ambient air temperature (Yellow Springs Instrument Co, model 401 with Bendix Friez recording hygrothermograph), net radiation (Swiss-teco model s-1 net pyrradiometer), barometric pressure (Weather Measure Corporation model 3211 recording microbarograph), precipitation (Weather Measure Corporation model P511-E), windspeed and wind direction (Climet Model CI-25 wind measuring system with model 011-1 windspeed transmitter and model 012-10 wind direction transmitter), dewpoint (EG&G International model 880), soil moisture, thermal conductivity, and heat capacity.

The RAMS turbulence study was conducted in July, August, October, and November of 1976. The fluctuations in temperature and wind velocity components were continuously measured by a Fenwall fast-response thermistor and a Gill UVW propeller anemometer at 30 m. Data was collected at towers 105, 107, 109, 111, and 113. The turbulence study data is not yet available on magnetic tape.

Planetary boundary layer (PBL) profilers were in operation from February 1975 until January 1976. During this time a total of 208 profiles were made. The profilers consisted of tethered balloons that were raised and lowered through 750 m. The profilers were located downtown and in a rural location well to the east of metropolitan St. Louis. On the profiles, temperature and dewpoint were measured by a ventilated bead thermistor in a radiation shield and by a wick-covered thermistor. On the ground at both sites was windspeed and wind direction equipment. The profiler data resides at the Illinois State Water Survey.

In conjunction with RAPS, a number of local meteorological measurements were made. These included the NWS station at Lambert Field and stations at Alton Civic Memorial (ACMA), Spirit of St. Louis (SSA), and Parks Bi-State (PBA) airports. In addition, instruments were located at the Gateway Arch (GAIS), Scott Air Force Base (SAFB), and St. Louis University (SU). The above had hourly observations except for GAIS and SU which had one daily observation. All instruments were located at standard heights except for SU which was at 9 m above the ground. The measurements made are summarized below:

NWS: Cloud height (Cruise-Hinds ceilometer), barometric pressure (H. J. Green mercurial barometer), ambient air temperature (Weston resistance thermistor), dewpoint (NWS dewpoint cell), relative humidity (psychrometer), ambient radiation (Victoreen geiger counter), windspeed and wind direction (Electra Speed F-420 wind system).

ACMA: Cloud height (Cruise-Hinds ceilometer), wind direction and windspeed (Electra Speed F-420 wind system).

SSA: Cloud height, windspeed, and wind direction (instruments same as ACMA).

PBA: Windspeed and wind direction (instrument same as ACMA).

GAIS: Daily maximum and minimum temperature (Weksley thermometer).

SAFB: Barometric pressure (ML-563 recording barograph and an ML-572 mercury barometer), ambient air temperature (TMQ-11 electrical resistance thermistor), dewpoint (TMQ-11 dewpoint cell), windspeed and wind direction (3AN/GMQ-20 transmitter with an RO-3[illegible]2 recorder).

SU: Daily maximum and minimum temperature (Weksley thermometer).

LGC: Windspeed and wind direction (recording manometer), ambient air temperature (Foxborough recording thermometer), net incoming solar radiation (pyrheliometer), soil temperature (thermistors).

MCC: Windspeed and wind direction (Bendix system).

UEC: Windspeed and wind direction (Friez Aerovane model 120), ambient air temperature (Leeds-Northrup thermocouple).

The instrument sitings were as follows:

LGC: All instruments are on the roof of Laclede gas building except soil probes that are at depths of 23 and 46 cm.

MCC: Approximately 8 m above ground.

UEC: Locations 1, 3, and 4 are at about 3 m. Location 2 is at approximately 76 m.

Finally the form of this data and its availability:

LGC: Strip charts--must be cleared with LGC before release

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Laclede Gas Company
3950 Forest Park
St. Louis, MO 63108
(314) 658-5480

MCC: Strip charts

Clarence Buckley
Monsanto Chemical Company
Sanget, IL 62201
(618) 271-5835

UEC: Magnetic Tape

Michael L. Manne
Union Electric Company
Environmental Sciences Department
PO Box 149
1901 Gratiot Street
St. Louis, MO 63166
(314) 621-3222, X2816

St. Louis, Missouri--METROMEX

METROMEX (Metropolitan Meteorological Experiment) was a large observation program sited around St. Louis, Missouri[38,39,40,41,42] Metromex was primarily concerned with urban effects on precipitation during a 5-yr study from 1971 through 1975. The Illinois State Water Survey was primarily responsible for conducting and archiving Metromex though many other agencies took part.

Relevant Metromex data networks include those for surface temperature, humidity, windspeed, and wind direction. Other networks included lidar and acoustic sounders, pilot balloons, radiosondes, and aircraft. The bulk of observations were made during July and August of each year, though surface network and some aircraft data was collected year round. The types of relevant observations are generally the same for the 5-yr period. The surface hygrothermograph network of 7 stations in 1971 was increased to 26 for 1972 through 1975.

The upper air network consisted of 3 or 4 rawinsondes and from 7 to 11 pibals depending on the observation period. 1972 had 17 pibal sites and 4 rawinsonde sites while 1973 had up to 13 pibal and 3 rawinsonde sites. Not all the pibal sites were used simultaneously.

The 1972 operations consisted of:

A. Convective Shower
   Number of Operations: 6
   Time: Approximately 1400 to 1900
   Observations:
   - 7 sites--Double theodolite pibals at 1/2-h intervals, to 3500 m.
   - 3 sites--Radiosondes at 1-h intervals tracked to 600 mbar. Five to six releases from each site, with one fewer from the central city.

B. Night-time Urban Circulation
   Number of operations: 5--clear light winds

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[38] W. P. Lowry, 1973, "1972 Operational Report for Metromex," Illinois State Water Survey, Urbana, IL

[39] W. P. Lowry, 1973, "1973 Operational Report for Metromex," Illinois State Water Survey, Urbana, IL

[40] T. J. Henderson and D. W. Duckering, 1976, Metromex 1975 A Summary Report. Report prepared for the Illinois State Water Survey, Urbana, IL

[41] R. R. Braham, Jr, 1972, "University of Chicago Contribution to Project Metromex-I," Prepared for the National Science Foundation, Washington, DC

[42] S. A. Changnon, Jr, F. A. Huff, and R. G. Semonin, 1971, "Metromex: An Investigation of Inadvertent Weather Modification," Bull Am Meteorol Soc, 52:958-967

Time: 2140 to 0100, one 2340 to 0300
Observations:
  7 to 9 sites--Double theodolite pibals at 20-min intervals to 2 km
  3 sites--Radiosondes at 1-1/2 to 2-h intervals tracked to 600 mbar.

C. Urban plume
   Number of operations: 4
   Time: 1220 to 1530 or 1400 to 1700
   Observations:
     7 or 8 sites--Double theodolite pibals at 20-min intervals to 2km
     2 or 3 sites--One radiosonde per operation, no radiosonde at site 2 during 1220 to 1530 operation.

The surface hygrothermograph and wind network and upper air network data are in the possession of the Illinois State Water Survey, Champaign, Illinois. Unfortunately, the data is unavailable in its present form.

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Acoustic sounding data was taken at the Granite City US Army Base from July 20 to August 25, 1972. In 1973 there were three sites, one as in 1972 at Granite City, one at the Gateway Arch in St. Louis, and one at the Scott Air Force Base MARS radio station. Acoustic sounding data was taken by Argonne National Laboratory.

Surface and upper air data were also taken at Granite City in 1972. The equipment included a Bendix-Friez hygrothermograph and Aerovane. A radiosonde was also launched at Granite City. In 1973, surface values for wind, temperature, and relative humidity were taken at the three acoustic sounding sites. Solar radiation was measured only at Granite City with an Eppley pyranometer.

Also at the Granite City site was a lidar operated by the Stanford Research Institute (SRI). The SRI lidar was operated extensively between August 7 and August 25, 1972. The sampling rate was generally three pulses per minute in the earlier observations and five or above per minute in the later observations. The lidar data together with the Argonne National Laboratory wind, temperature, humidity, and radiation measurements were recorded at 1-min averages during the complete experimental period.

During Metromex, the University of Chicago surveyed the urban heat island with aircraft. The surveys were conducted in both summer and winter months. One aircraft was the University of Chicago Lodestar N9980F which measured air temperature and humidity. The other aircraft, the Queen Air 304D, was provided by the National Center for Atmospheric Research (NCAR) which measured surface temperatures.

On board the Queen Air was a Barnes PRT-5 radiometer which provided infrared detection of surface temperature anomalies. A microfilm record of radiation temperature and position at 1-s intervals was generated. The position data is very accurate.

Cross-sectional flights were generally taken on days with light wind when it was thought that the urban effect would be at its maximum. A typical flight consisted of a sequence of runs at several levels up to 5000 ft above sea level along a track about 40 mi long and generally normal to the prevailing wind direction.

There were three temperature sensors on the Lodestar; a Rosemount 102E2AL; a platinum resistance element circuit with range switching; and another platinum resistance element without range switching. Humidity on the Lodestar was measured by a model 137-63 Cambridge Frost Post Hygrometer with a 137 to 510 sensor, and by a wet bulb platinum element. Measured temperatures were corrected to account for altitude variations. Any existing mesoscale temperature variation was assumed to be the linear trend between the start and finish points of a cross-sectional flight. Any variation from the linear trend was attributed to the urban influence.

At the beginning of a run, the aircraft position and time with respect to a well-defined point was marked. The aircraft then flew the cross section at roughly constant altitude. At the end of the run position and time were again marked. The altitude was then increased by 500 to 1000 ft and another run over the same flight path done. During the runs, data was continuously recorded on a multichannel analog and digital magnetic tape system adapted from the NCAR ARIS II. This was converted into a computer compatible ground tape and processed to give a microfilm output record.

Uppsala, Sweden

The UUMP Project[43 44 45 46] was begun in 1972 with one of its purposes being the study of the development of the three-dimensional structure of urban wind and temperature fields. The main periods of observation were May, June, September, and October 1976. Uppsala is a small city covering an area of about 21 km^2 and has a population of approximately 100,000. It is located at latitude 59°55' north and longitude 17°36' about 80 km from the Baltic Sea. The surrounding countryside near the city is mostly open fields with forest predominating further away from the city. The terrain is very gentle with the greatest variation in the southwestern part of the city.

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[43] U. Högstrom et al, 1978, "The Uppsala Urban Meteorology Project," Boundary Layer Meteorology, 15:69-80

[44] R. Taesler and S. Karlsson, 1980, Power-Law Estimates of the Urban Wind Profile, Report 59, Department of Meteorology, University of Uppsala, Sweden

[45] R. Taesler, 1980, Studies of the Development and Thermal Structure of the Urban Boundary Layer in Uppsala. Part I, Experimental Program, Report 61, Department of Meteorology, University of Uppsala, Sweden

[46] S. Karlsson, 1980, Analysis of Wind Profile Data from an Urban-Rural Interface Site, Report 58, Department of Meteorology, University of Uppsala, Sweden

There are virtually no tall buildings in Uppsala, the tallest mentioned being a hotel of seven stories. The commerical area is generally characterized by buildings of three to six stories while the outlying residential areas have building heights of two to four stories, decreasing to one to two stories for single-family homes. With the ground elevation rising gently from the city center eastward, and with the average building height decreasing, the net effect is that the average rooftop level is nearly horizontal. The Uppsala observations consisted of a meteorological tower, a fixed and mobile surface mast, surface thermograph network, wiresondes, pibals, and smoke puffs.

The Gränby tower made continuous measurements of air temperature, vapor pressure, and windspeed at 1, 2.7, 7.3, 20, 35, 50, 75, and 100 m above ground. Wind direction was measured at 7.3, 50, and 100 m. The anemometers on the mast and the wind vanes were placed on booms projecting 1.5 m from the tower. Global and net radiation measurements were made at the tower site at 1.5 and 1.0 m above the ground, respectively, and a ground heat flux measurement was made at 1 cm below the ground. The Gränby tower data is available on magnetic tape in both 4-min and hourly averages.

Net radiation and global radiation were measured with a CSIRO net radiometer and a Moll-Gorszinsky radiometer, respectively. Ground heat flux was measured with four CSIRO ground heat flux plates buried around this area.

A modified Casella sensitive anemometer was used for measuring windspeed. The instrument was made weatherproof and durable by replacing the original cup rotor arms with delta-shaped flat arms made of aluminum, and by replacing the original jewel bearings with miniature ball bearings. Wind tunnel calibrations showed that these modifications had no effect on the sensitivity or the distance constant. The eight anemometers used in Gränby were calibrated individually over the windspeed range 0.5 to 35 ms^{-1} before they were installed on the mast, and again after 1-1/2 yr of continuous operation. The recalibration gave a satisfactory result: the difference between the two calibrations was entirely random and of the order of the accuracy of the wind tunnel speed determination, that is, about 1 percent for windspeeds above 4 ms^{-1} and better than ± 0.05 ms^{-1} for lower windspeeds.

The temperature and humidity measuring system consisted of three sets of 500 Ω Pt-sensors. One set was placed in ventilated shields at the air intakes for measuring the air temperature at the various levels; the other two sets provided measurements of "dry" and "wet" bulb temperatures, and were placed in a special screen at the base of the mast.

A low-level radiosonde (Vaisala RS17) was used for temperature soundings at the Meteorological Institute. The sonde had a fast response wire-thermometer that in conjunction with a manual receiver allowed a resolution of $\pm 0.1°C$. A 1000 g sounding balloon carried the sonde and measurements were generally done in light wind conditions of less than 6 ms^{-1}. While the balloon had a maximum height of 350 m, it was generally confined to 200 m or below. Ground checks were taken at least before and after each sounding. The soundings were done by repeated ascents and descents with stops for every 10 m, or in some cases, 20 m of tether-line length. Each stop lasted for 1 min and readings were taken at the end of the 1-min stop in order to allow the sensors to stabilize. The inclination of the tether-line from the vertical was estimated at each stop, which together with the length of tether-line provided an independent estimate of the height of measurement.

Mobile temperature measurements were made on a 14-m telescopic mast attached to a car. Temperature was measured at 2.2, 7.4, and 14 m. Due to the sampling method used, the temperature differences between two levels may be in error by ±0.1°C. Measurements were made at 4 to 6 of 11 preselected sites during a time period of 3 h. At each site, a temperature level was sampled for a 10-s period every 30 s for about 15 min. Primary readings were transferred to punch cards, and mean values calculated for each 15-min period.

An attempt was made to study the wind field associated with the urban heat island, and in particular, the possible development of an urban circulation by observations of smoke puffs released at ground level. These experiments were only done on a few occasions, when the heat island was particularly well-developed and the general flow of air was less than 2 ms^{-1}.

The smoke puffs were released during stops in the temperature survey at open spaces around the main built-up area. They were thus not done simultaneously at all points, but successively during a period of a few hours. To make simultaneous smoke observations at all points would have required several more participants and would have hampered other parts of the experimental program. To reduce, as far as possible, the effect of nonstationarity in the wind field, successive puffs were released in a criss-cross fashion by moving from one side of the main built-up area to the opposite.

The smoke was generated for about 30 s but could be observed for a period of a few minutes, during which the direction of movement was determined by compass readings and the dispersion character observed.

Thermographs were placed at sites RÅ, HJB, VA, FL, MI, F16, and MARSTA as shown in figure 5. Continuous records were taken at all but the latter two sites where values were obtained hourly. Recordings at MI were on a continuous basis while those at the first four sites were done only when favorable weather was expected.

The data from F16 are regular, hourly synoptic observations of good quality. The stations MI and MARSTA are run by the Meteorological Institute and the recordings are corrected by taking reference readings several times daily with a ventilated Assman psychrometer.

The screens used at RÅ, HJB, VA, and FL had no mechanical ventilation. Thus, they were expected to have produced radiation errors during conditions of bright sunshine and weak winds. This may have been the case with the screen at RÅ, which was in a rather sheltered position.

In the center of the city on the seven story Uplandia hotel, temperature, windspeed, wind direction, and net radiation were measured at 14 m above the roof. Global radiation was measured with a standard Moll-Gorzinsky pyrradiometer. The instrument was calibrated during May 1976 and the accuracy of the measurements were estimated to be approximately 5 percent.

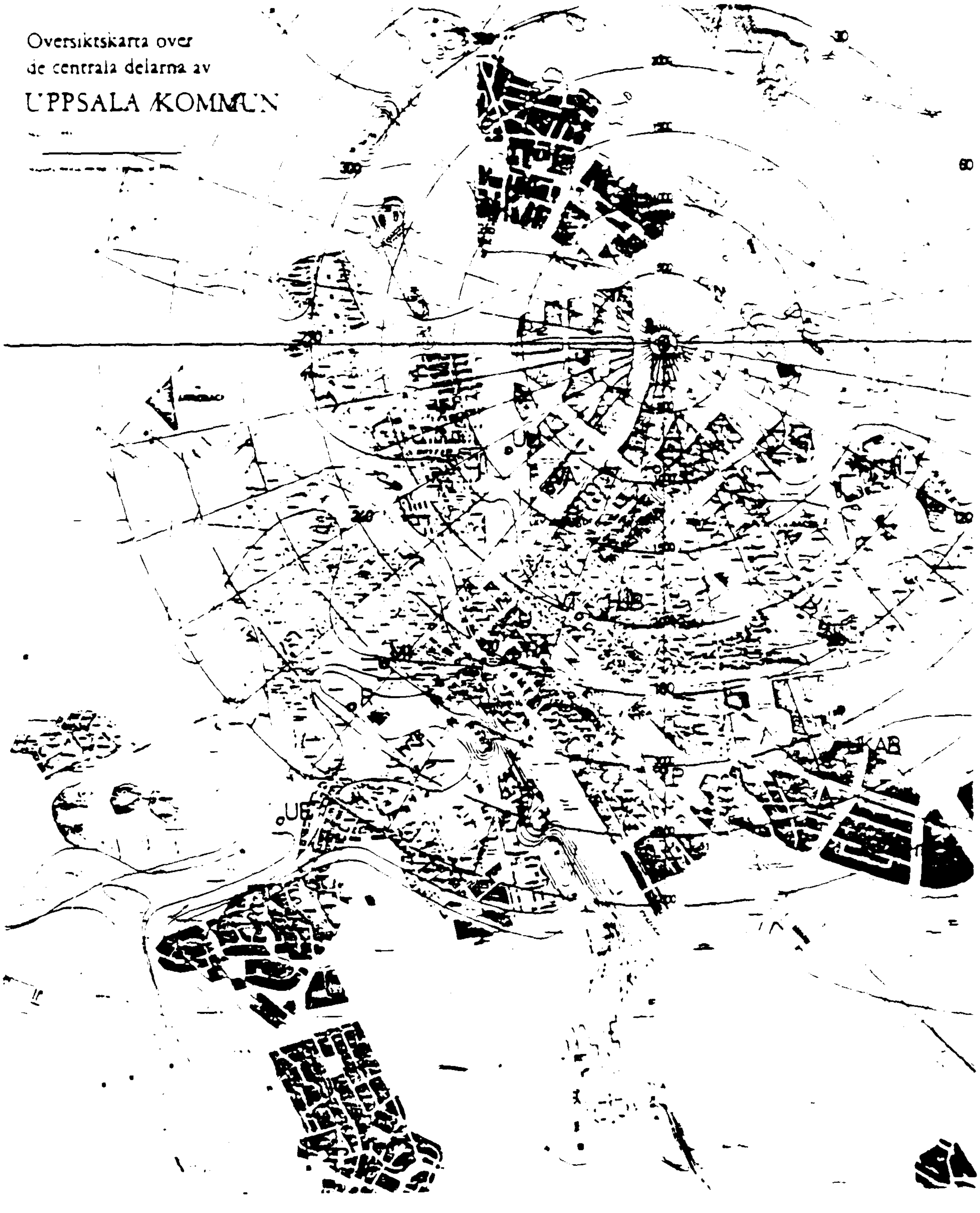

Figure 5. Uppsala Thermograph Sites (after [illegible])

Net radiation was measured with a CSIRO net radiometer. The recorded output was evaluated according to the original, individual calibration certificate provided by the manufacturer. The accuracy is believed to be about 5 to 10 percent, but no direct check of this could be made.

Windspeed was measured with a standard Cassella cupanemometer. The threshold wind velocity for this instrument is about 0.2 m/s and the accuracy of measurement is about ±0.05 m/s at windspeeds less than 5 m/s and about ±1 percent at higher speeds. Calibration of the anemometer was done in the same wind tunnel as with the anemometers used at Gränby. Wind direction was measured with a potentiometer and a wind vane. The instrument is identical to the ones used by Granby. The accuracy of measurements is estimated to be about 5 degrees. All data were recorded on a data-logging system with paper tape as output. The logger scanned all the channels once every 6 min, thus allowing continuous recording for about 1 wk.

The primary recordings were later processed on the IBM 360/370 computer at Uppsala University. One-hour mean values were computed for each channel and listed together with the primary data.

The mast used on the rooftop was of the same type as the one used for the mobile profile measurements. The surrounding, central urban area is rather homogeneous in all directions up to 500 m distance or more with an average building height of about 15 m.

Another problem that could not be eliminated was caused by a ventilation outlet on the roof. From this outlet, warm air could be advected towards the mast with winds from directions between 150 to 200 degrees.

Some pibals were released during the early stages of the experimental program. The balloons were released from the Gränby site during periods with winds toward the urban area. One experiment comprised a series of balloons released during a period of 1 to 2 h. Each balloon was followed over a period of 15 to 40 min during which it rose to a height of 1 to 1.5 km. Readings were taken simultaneously every 30 s at the two theodolite-sites. To obtain simultaneous readings, the procedure was directed by radio communication. Readings of azimuth and elevation could be done with a precision of ±0.1 degree. In addition, the accuracy of the measurement depends on an individual's ability to track the balloons, on the timing of readings, and on the angle between the lines of sight.

The balloons in a series were inflated differently using hydrogen gas to cover a range in speed of rise from 25 m/min to 100 m/min. The free lift and speed of rise of the balloons was determined by balancing the buoyancy of each balloon against a given, preselected weight.

The primary readings were transferred to punched cards and subsequently run on the computer to obtain windspeed and wind direction for each 30-s interval. In addition, the program provided data on the xyz-coordinates for the balloon and on the errors in these coordinates.

Measurements were taken during both day and night. In the latter case a lamp powered by a small 1.5 V battery was attached to the balloon. Measurements were confined to cases with weak or moderate windspeeds less than 8 m/s. At higher speeds the tracking of the balloons was found to be rather difficult.

resulting in poor accuracy of the readings during the first minutes after release.

Some statistical analysis of the Gränby tower wind data has been done. The data was collected over a 2-yr period from 1974 to 1976 representing about 30 percent of the days. Data was classified in terms of both stability and/or wind direction classes. The stability classes were calculated on the basis of the Richardson number, while the eight wind directions depended on the type of upwind fetch and cover from 20 to 80 degrees of view. The standard deviation of windspeed was calculated from

$$\sigma_u = \bar{u} \int_{z_0}^{z} \frac{\phi_m}{z} dz$$

where ϕ_m is dependent upon stability.

It has been learned that Gränby tower and turbulence data are available from Professor Ulf Högstrom at the University of Uppsala. Presently the tower data is stored as hourly means on punched cards. Some measurement errors may exist in the data set. The turbulence data is stored on magnetic tape. All other data including the wiresonde, thermograph, pibal, and rooftop data are available from Dr. Roger Taesler at the Swedish Meteorological and Hydrological Institute in Norrköping. All of the above are either on punched cards or computer printouts.

OTHER URBAN METEOROLOGICAL OBSERVATION PROGRAMS

Many other additional observation programs have been conducted. The following programs did not observe the vertical variation of wind, temperature, and relative humidity, and consisted of a very limited number of observations. Delineating the magnitude of a particular cities' heat island was the primary goal in several of the following programs.

Bombay, India
Canadian Tower Network
Chapel Hill, North Carolina
Cheyenne, Wyoming
Cologne, Germany
Columbia, Maryland
Dayton, Ohio
Dallas, Texas
Denton, Texas
Denver, Colorado
Freiburg, Germany
Giessen, Germany
Greeley, Colorado
Helsinki, Finland
Johnstown, Pennsylvania
Kansas City, Missouri
Koide, Japan
Liége, Belgium
London, England

Los Angeles, California
Mexico City, Mexico
Minneapolis, Minnesota
Nagano, Japan
Oklahoma City, Oklahoma
Paris, France
Plymouth, England
Poona, India
Rome, Italy
San Francisco, California
San Jose, California
Stuttgart, Germany
Tokyo, Japan
Tsukuba, Japan
Toronto, Ontario
Utrecht, The Netherlands
Venice, Italy
Vienna, Austria
Washington, DC
Winnipeg, Manitoba

Poona and Bombay, India

Mobile temperature surveys of Poona and Bombay revealed heat islands.[47] The surveys were done on only a few occasions and fixed observations of wind and temperatures were limited to just one or two stations in each city. No vertical profile data were taken.

Minneapolis, Minnesota; Cheyenne, Wyoming; and Greeley, Colorado

Heating season (December through March) data were collected at 19 stations: Minneapolis, Minnesota (2 seasons--Jan 13, 1979 to Mar 31, 1979 and Dec 1, 1977 to Feb 28, 1978); Cheyenne, Wyoming (2 seasons and 6 stations); and Greeley, Colorado (3 seasons and 7 stations).[48] Temperatures were observed at all stations, and wind direction and windspeed at most stations. The temperature data were obtained with thermographs in standard screens and continuous records of wind were obtained with anemometers, generally at 3 m above the surface. Also, the data for Minneapolis and for one season in Greeley include tower temperature and/or wind data. The 152-m Minneapolis tower data consists of three levels of wind and temperature at 21, 37, and 153 m. The recorder charts were processed into bihourly mean values.

Much of the monitoring equipment used in the program was supplied on loan by the NCAR and by the US Forest Service. A shortage of equipment forced the leasing of several items. All equipment not already in place and operating

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[47] C. E. J. Daniel and K. Krishnamurthy, 1973, "Urban Temperature Fields of Poona and Bombay, India," Meteorol Geophys, 24(4):407-412

[48] E. R. Reitar et al, 1980, "The Effects of Atmospheric Variability on Energy Utilization and Conservation," Environmental Research Papers [illegible], Colorado State University, Fort Collins, CO

independently from the program was calibrated on installation. Temperatures were recorded by sheltered mechanical thermographs at a uniform height of 1.5 m. Windspeed and wind direction sensors were at elevations ranging from 3 to 10 m. The thermographs were routinely checked against calibration thermometers during the program by the network operators. To allow for better comparisons between individual instruments, all thermographs were carefully transported to a common site and operated side-by-side for 3 d at the end of the program.

Data were reduced to hourly or bihourly values and corrected for calibration and other systematic errors. The data from the television tower seems to have some inaccuracies in the temperature data.

Although archives of these data are retained, the program has been terminated and resources to easily generate digital tape copies do not exist. However, photo copies of data for some years and cities can be provided by

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In another experimental program, vertical temperature data were taken on a television tower located on the boundary of St. Paul and Minneapolis in the heart of the metropolitan area.[49] Temperature was measured at 70, 170, and 500 ft above ground level by shielded resistance thermometers. The data was recorded on Leeds and Northrup model G strip chart recorders at 2-min intervals. The data was used to study inversion frequency, onset, duration, and intensity.

Canadian Tower Network

The Canadian tower network consisted of a number of towers instrumented with meteorological sensors. The towers' locations ranged from rural to urban and their particulars are summarized in table 5.

The data was collected and archived by Atmospheric Environment of Canada, however, data collection ended in February 1976. Some of the tower data is discussed further in sections dealing with Edmonton, Calgary, Hamilton, Toronto, Montreal, and Winnipeg.*

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[49]D. G. Baker and J. W. Enz, 1969, "Frequency, Duration, Commencement Time and Intensity of Temperature Inversions at St. Paul-Minneapolis," J Appl Meteorol, 8(5):747-753

*J. McClaren, 1982, personal communication

TABLE 5

CANADIAN TOWER NETWORK

Location	Latitude Longitude and Elevation	Sponsor	Exposure	Wind Instrumentation	Average Time for Data
Vancouver	49°19'N 123°08'W 264'	National Harbours Board	Top of Lions Gate Bridge, Burrard Inlet	Canadian Met. Service Type U2A	Hourly instantaneous
Calgary	51°01'N 114°01'W 3175'	Alberta Department of Health	Urban	R.W. Munro	Temp--Hourly averages of 10-min. readings Wind--1-Hourly average
Edmonton	53°33'N 113°29'W 2175'	Alberta Department of Health	Urban	R.W. Munro located on top of 365' building on 12' tower	Temp--Hourly averages of 10-min. readings Wind--1-Hourly average
Primrose Lake	54°45'N 110°03'W 2303'	Department of National Defence	Hilly area, scattered 15' second growth, ½ mile south of lake	Canadian Met. Service Type U2A	Hour to 10 mins. past
Suffield Tower	50°16'N 111°03'W 2348'	Defence Research Establishment	Rural	Bendix-Friez	Hour to 10 mins. past
Whiteshell	50°11'N 96°04'W 855'	Atomic Energy of Canada Limited	Rural	Bendix-Friez	5 mins. to the hour to 5 mins. past
Winnipeg (CBC-TV)	49°46'N 97°31'W 785'	Dept. of Geography, University of Winnipeg	Rural	Bendix-Friez	Hour to 10 mins. past
Hamilton	43°15'N 79°46'W 250'	Air Management Branch, Ont. Dept. of E.R. Management	Urban	Bendix-Friez	Hour to 10 mins. past
Ottawa	45°24'N 75°41'W 260'	Occupational Health Div., Dept. of N.H.&W.	Suburban	Bendix-Friez	Hour to 10 mins. past
Sarnia (Courtright)	42°48'N 82°29'W 590'	Air Management Branch, Ont. Dept. of E.R. Management	Rural St. Clair River	Bendix-Friez	Hour to 10 mins. past
Toronto (CBC-TV)	43°40'N 79°23'W 340'	Atmospheric Environment Service	Urban Buildings 100-150 ft. in vicinity	Bendix-Friez	Hour to 10 mins. past
Toronto (Met. Research Station)	43°48'N 79°33'W 635'	Atmospheric Environment Service	Rural	Bendix-Friez	Hour to 10 mins. past
Toronto (Mimico)	43°37'N 79°[illegible]'W 350'	Air Management Branch, Ont. Dept. of E.R. Management	Suburban	Bendix-Friez	Hour to 10 mins. past
Windsor	42°16'N 83°06'W [illegible]	Air Management Branch, Ont. Dept. of E.R. Management	Rural, Detroit River	Bendix-Friez	Hour to 10 mins. past
Montreal (Botanical Gardens)	45°34'N 73°34'W 180'	Division of Industrial Hygiene, Quebec Ministry of Health	Suburban	Bendix-Friez	10 mins. to the hour to 10 mins. past
Montreal (CBC-TV)	[illegible]	Met. Service McGill University	Top of 700' Mount Royal	Bendix Friez	10 mins. to the hour to 10 mins. past

*All [illegible] resistance bulbs

Chapel Hill, North Carolina

The heat island was studied in Chapel Hill[50] by an instrumented automobile. On the automobile, a Westerup resistance thermometer was placed inside a Climet radiation shield and mounted on the right front bumper 1-1/2 m above the road. Traverses were conducted late in the evening and temperatures were periodically read and coordinated with position. A dozen traverses covering the winter, spring, and summer seasons were done.

Cologne, West Germany

From June 1978 to June 1980 the inversion structure heights were measured continuously with two sodars.[51] The sodars were both Aerovironment models 300 using a sound frequency of 1600 Hz. One was mounted on a roof close to the center of Cologne. It provided a continuous time series for more than 4 yr. The other sodar was installed at the "water supply station Weiler," which is about 12 km northwest of Cologne in a rural environment.

To verify the inversion statistics, several parallel soundings with a tethered sonde were made. Digitized data were stored on cassette tapes for analysis on a Hewlett-Packard desk calculator.

Columbia, Maryland

Columbia is a planned community located between Baltimore and Washington. Columbia was originally rural land but had grown from 200 in 1967 to 22,000 in 1975. It is expected to eventually reach a population of 100,000.

From 1967 to 1975 measurements were made periodically.[1] Equipment primarily consisted of two Meteorology Research Incorporated automatic weather stations in fields and six cooperative observing stations at which maximum and minimum temperatures were observed in louvered shelters.

Occasional mobile surveys yielded temperatures at 17 fixed points. A shielded thermistor was mounted on the automobile hood. A mobile windspeed was also taken at the 17 points with a Wallac OYGGA22/F instrument. Radiation balance was measured with either a Thornwaite Associates net radiometer or with a Funk model net radiometer manufactured by Swissteco.

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[50] R. J. Kopec, 1970, "Further Observations of the Urban Heat Island in a Small City," Bull Am Meteorol Soc, 51(7):602-606

[51] R. Dohrn et al, 1982, "Inversion Structure Heights above the City of Cologne (Germany) and a Rural Station Nearby as Measured with two Sodars," Meteorol Rdsch, 35:133-144

[1] H. E. Landsberg, 1981, The Urban Climate, Academic Press, New York

Finally, vertical wind was measured by a three level Thornwaite Associates micrometeorological set on a telescoping mast. Two thermistors at 2 m and 20 m measured the temperature.

Dayton, Ohio

Dayton is a medium sized metropolitan area having a metropolitan population of about 800,000. The major terrain feature is the Miami river valley which runs through the Dayton area. The area outside Dayton is generally agricultural with corn and soybean farming predominating. In conjunction with the Dayton Climate Project, a survey of meteorological data and collection sites in the Dayton area was done.*

The NWS office is located at the Dayton International Airport in Vandalia, Ohio, about 8.5 air miles from downtown Dayton. The instruments used in obtaining the data are located 50 to 75 ft away from the main runway and are well away from buildings or trees. Elevation of the site is 995 ft above mean sea level. The latitude/longitude of the NWS site is 39°54' north latitude and 84°12' west longitude. Wind is obtained at 22 ft, relative humidity at 4 ft, and temperature at 6 ft above the ground. This location has been used since February 1974.

Temperature, dewpoint, relative humidity, visibility, and precipitation are observed and recorded every 3 h. The average station pressure is available on a daily basis only. Also available from the NWS data are minutes of sunshine and percent of possible sunshine.

The data at Wright-Patterson Air Force Base can be obtained through the NCC. The instruments are located near a runway situated near the center of the base in a relatively flat and very open area at an elevation (above mean sea level) of 810 to 820 ft. The thermometer/dewpoint recording devices are 6 ft above the ground about 800 ft to the southeast of runway 23. The wind instruments are about 600 ft from the runway at a height above the ground of 13 ft. The pressure is taken inside the office about 3/4 mi southeast of the runway. The runway itself lies in a flat, open field that extends for nearly 3 mi in length in a northeast-southwest orientation with the width at about 1 mi. The field sits below small hills to the west-east-south that rise upwards from 900 to 980 ft.

The data gathered includes: temperature, dewpoint, pressure, windspeed and wind direction.

The Regional Air Pollution Control Agency (RAPCA) data was obtained from the top of the 13-story Montgomery County Administration Building on West Third Street in downtown Dayton. The building is relatively isolated from other buildings and is within 200 ft of interstate highway 75. The building is approximately 150 ft above the ground elevation (745 ft mean sea level elevation) and the instruments for windspeed and wind direction are about 20 ft above the roof of the building (total elevation from mean sea level to top of instruments about 915 ft-estimated).

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*J. Clemens, A. Perry, and S. Marcum, 1982, personal communication

The only data available here is windspeed and wind direction. It is relatively complete considering the time covered, but there are several days in certain months missing, especially toward the end of December and the beginning of January 1977.

The Montgomery County Air Pollution Control Agency (MCAPCA) data were obtained from a trailer located in a school bus parking lot at Northridge High School on Timberland Road. The trailer sat down in a basin and was surrounded by various buses, trucks, telephone poles, oil drums, and 6-ft fencing. One hundred feet north of the trailer was a football field about 10 to 12 ft higher than the spot where the trailer was located. At about 600 to 700 ft west was the Northridge Middle School, an older building three stories in height that was about 30 ft higher than the trailer's elevation. To the east and northeast there were additional fields and buildings (150 to 300 ft distant) that rose 5 to 15 ft above the trailer's elevation. The only relatively open area was to the SW-S-SE. The elevation of the site is 835 ft above mean sea level with the windspeed and wind direction instruments located about 15 to 20 ft above the ground.

The Dayton Power and Light Monument office is located in an older building about three stories in height on Monument Street in the northeastern portion of downtown Dayton. The building is within 500 ft of the Mad River and sits down below a hill immediately to the north of the building.

The data taken at the Monument Street location include: temperature, relative humidity, and pressure recorded at 3-h intervals. This data is mostly continuous although there are a few days missing from the record. It is more complete than the RAPCA or MCAPCA data. The relative humidity instrument is almost certainly questionable. Readings of 10 to 15 percent are very frequent in the summer months which are certainly low for this area.

The NWS rawinsonde balloon was launched from Taylorsville. The launch site was about 10 mi north-northeast from the center of Dayton in a rural area. The surrounding countryside is rolling. The balloons were launched twice daily in conjunction with world-wide upper air launches at 0000 and 1200 Greenwich Meridian Time. Temperature and dewpoint were observed at balloon launch times. The rawinsonde data both in summarized and raw form are available from the NCC in Asheville, North Carolina.

Because of its work with hazardous materials, the Mound Laboratories makes continuous measurements of wind, temperature, and dewpoint. The laboratory is located on top of a large hill overlooking the Miami river. Meteorological measurements are made on a 120-ft tower that is mounted on top of a 42-ft building. Wind direction, temperature, and dewpoint are measured at the 60 ft level, while windspeed and temperature are measured at the 120-ft level. The data are available on strip charts from the laboratory.

Dallas, Fort Worth, and Denton, Texas; and San Jose, California

Ludwig performed heat island studies at Dallas, Fort Worth, and Denton, Texas; and San Jose, California.[52,53] The bulk of observations were performed in Dallas. The studies were done in July and August, 1967. In general the data is limited to automobile wet and dry bulb temperature traverses along two perpendicular lines generally southwest to northeast and northwest to southeast in each city. Additional data includes a hygrothermograph at Love Field in Dallas, and hourly values of all the meteorological variables at Greater Southwest International Airport, Meacham Airport, and Carswell Air Force Base in Ft. Worth, Texas. Finally, a pyrheliograph was placed on the terminal building at Love Field, Dallas, Texas.

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Denver, Colorado

A limited surface observation system of 20 wind and temperature stations collected data for a total of 60 days during December 1964 to April 1965 and during December 1965 to April 1966 in Denver.[54] In conjunction some tetroon data is also available. The data is not archived and land use classification is likely difficult. In another observation program, special radiosonde soundings were taken at noon near the center of Denver from 1971 to 1973.[55]

Freiburg, Germany

A limited amount of observational data has been obtained at Freiburg, latitude 48°N and longitude 7°E.[56] Data was obtained at two sites--one located at the center of the city and the other 4 km away outside the city.

Surface measurements consisted of temperatures at a height of 7 m (windspeed was not observed at the city center site). In addition, a tethered balloon

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[52] F. L. Ludwig, 1967, Urban Climatological Studies Interim Report 1, Contract OCD-PS-64-201 under work unit 1235A, Stanford Research Institute, Stanford, CA

[53] F. L. Ludwig and H. M. S. Kealoha, 1968, Urban Climatological Studies Final Report, Contract OCD-DAAC-20-67-C-0136 under work unit 1235A, Stanford Research Institute, Stanford, CA

[54] H. Riehl and D. Herkhof, 1972, "Some Aspects of Denver Air Pollution Meteorology," J Appl Meteorol, 11(7):1040-1047

[55] P. L. Haagenson, 1978, "Meteorological and Climatological Factors Affecting Denver Air Quality," Atmos Environ, 13:79-85

[56] D. Ahrens, 1981, "Untersuchungen über die Warmeinsel and die Mischungsschicht einer Großstadt," Arch Met Geoph Biokl, Ser. B, 29:29-36

was used to determine vertical temperature gradient and mixing depth. Global radiation was also measured.

Apparently all data was recorded continuously except for that obtained from the tethered balloon. The availability of this data is uncertain. There should be little difficulty in categorizing the land use for the time that the observations were made.

Giessen, Federal Republic of Germany

Giessen is a rather small city of 75,000 with a metropolitan population of 100,000. It is located at 51°N and 9°E in quite hilly country. Data is limited to six thermograph stations on thermograph charts in and near Giessen.[57]

Helsinki, Finland

Urban meteorological data for Helsinki appears limited to a mobile temperature survey done on three frosty nights in February 1973.[58] The prevailing weather conditions favored a strong inversion so that the difference between the highest and lowest temperature was 13°C.

Johnstown, Pennsylvania

Johnstown is an industrial town located in a narrow valley of the Allegheny plateau. From July 1964 through February 1966 a modest program of air quality sampling and meteorological observations was carried out. A general time frame of 2 mo periods, primarily during fall and winter, was selected for intensive study.[59]

Two 150-ft towers provided windspeed at 50, 100, and 150 ft levels using small cup anemometers. Thermohms provided temperatures at 50 ft and 150 ft and bivanes were installed at the 100-ft level. A smaller tower on a low plateau was equipped with an aerovane at a height of 75 ft. An aerovane was also operated by the Pennsylvania Electric Company. Other weather information was available from the Johnstown airport located on a plateau 1000 ft above the city and about 4 mi to the east. In the summer of 1966 a small wind vane was operated in the valley of the Little Conemaugh River. Occasional smoke experiments were also carried out.

The data obtained during this program may be available in reports from Pennsylvania State University, which carried out an analysis of the observations.

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[57]R. Hermann and B. Meiser, 1973, "Untersuchungen über die Zeitliche und Ramliche Äderung des Temperaturfeldes im Stadtgebiet von Giessen," Die Erde, 3-4:226-246

[58]P. Fogelberg et al, 1973, "Observation of the Temperature Climate of Helsinki in Winter," Terra, 85:234-239

[59]H. A. Panofsky and B. Prasad, 1967, "The Effect of Meteorological Factors on Air Pollution in a Narrow Valley," J Appl Meteorol, 6:493-499

Kansas City, Missouri; Topeka and Lawrence, Kansas

Data available for Kansas City, Topeka, and Lawrence appears limited to automobile traverse studies. Measurements of temperature and relative humidity were made periodically from June 1971 to October 1972 in the early morning and early afternoon hours.[60] No vertical profile data is mentioned.

Koide, Japan

During the period of November 4 to 12, 1969, a number of auto traverses of the Koide heat island were done.[61] A thermistor placed near the front bumper yielded about 200 data points for each observation time. A large number of maximum and minimum thermometers were also placed in various parts of Koide.

Vertical temperatures were registered continuously at 5, 35, 55, and 90 m from recording electric psychrometers mounted on a microwave tower. The tower is located on the edge of the built-up area.

Liége, Belgium

Liége is a small to medium sized manufacturing city in eastern Belgium. The city has a population of about 150,000 with a metropolitan population of about 450,000. While Liege is sufficiently far inland to rule out influences from the seabreeze, it does lie in the Meuse river valley which is quite deep. The altitude difference between valley floor and ridge top is about 200 m (660 ft).

During a 1962 study,[62] temperatures were measured at the following fixed points:

Sart-Tilman--forest south of Liége (250 m)
St. Paul--cemetery of city in valley (60 m)
Mousin--in valley northeast of city center (60 m)
Tilff--in a tributary valley (80 m)

The temperature differences between these stations were classified according to synoptic weather types.

The only long term wind observation was made at a height of 15 m at Mousin. However, a special observation period with at least 8 anemographs located throughout the urban area was done.

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[60] J. R. Eagleman, 1974, "A Comparison of Urban Climate Modifications in Three Cities," Atmos Environ, 8:1131-1142

[61] T. Sekiguti, 1973, "Basin and City Climate Complex," Japanese Progress in Climatology, 3:14

[62] A. Hufty, 1973, "Types de Temps Synoptiques en Belgique et Climats Locaux à Liége," Societé Belge d'Etudes Geog, Ghent, Memoir 23

London, England

The Central Electricity Research Laboratory (CERL) has wind and temperature recorded on a tower near the Thames river in east London.* Data were recorded continuously from October 1964 through May 1966. Wind was measured at 129, 375, and 615 ft with temperature differences between three levels. At the same time, temperature gradients were recorded between 20 ft and 300 ft and 300 ft and 650 ft at Crystal Palace, which is located in southeastern London. The above data together with winds estimated at 900 m from the Crawley radiosonde are stored on IBM magnetic tape (9 track, 1600 bpi). Average hourly wind profiles are also stored on tape.

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Other London data** includes surface observations at five locations in London. At three locations, the wind, humidity, cloud cover, and temperature were recorded on magnetic tape available from the Meteorological Office. Hourly observations are available for periods ranging from 8 to 33 yr. Additional wind data may be available from London-Blackwell, London-Whitehall Gardens, and from the London General Post Office (GPO) tower. At the GPO wind was measured at 195 m above the ground.

Los Angeles, California

Meteorological data in the Los Angeles area is collected primarily by the South Coast Air Quality Management District. The South Coast Basin has nine and one-half million people in an area of 6,580 mi^2.

Hourly wind direction and windspeed are available for the Los Angeles area for several years. There are 35 wind reporting stations in the area with Bendix aerovanes perched atop 30 ft towers. Some of this data is available on magnetic tape from:

Jerry L. Arnold III
South Coast Air Quality Management District
Air Programs Division
9150 Flain Drive
El Marte, CA 91731
(213) 572-6364

*R. Pierce, 1982, personal communication

**S. F. G. Farmer, 1982, personal communication

Data from 60 wind reporting stations in the Los Angeles area was collected to derive hourly wind flow patterns.[63] Two to twenty-four years of data was available for the various stations. Solar radiation was observed at ten locations in the area. The data is available in daily radiation only from the above address. Thirty-five stations report temperature for climatological purposes but the reported temperatures are daily maxima and minima. Upper air data for winds and inversions aloft are available on request from:

Arndt Lorenzen
Associate Meteorologist
Air Resources Board
1102 Q Street
Box 2815
Sacramento, California 95812
(916) 322-7454

The soundings are generally taken at 0400 local time. Also upper air data is available from the NWS station at Los Angeles and other stations at Santa Monica, El Monte, San Bernardino, Riverside, and Pt. Mugu.[64]

At various times, upper air data was collected at 15 sites in the South Coast Air Basin. In general the periods of data collecting, however, do not overlap. All upper air data is available from either the NCC or the California Air Resources Board.

In conjunction with the Los Angeles Reactive Pollutant Project (LARPP), triads of tetroons were released simultaneously from the same point on the ground.[65] The tetroons were followed by helicopters which took air samples. A total of 35 tetroon triads were released.

During the Three Dimensional Pollutant Gradient Study, vertical profiles of temperature,[66] relative humidity, and turbulence were measured. The measurements were made from two aircraft performing spirals from the surface to the top of the polluted layer at 17 locations. About 40 spirals were performed at each location.

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[63] R. W. Keith and B. Selik, 1977, "California South Coast Air Basin Hourly Wind Flow Patterns," South Coast Air Quality Management District, El Marte, CA

[64] A. Lorentzen, 1979, "Summary of California Upper Air Meteorological Data," State of California, Air Resources Board, Sacramento, CA

[65] J. K. Angell, C. R. Dickson and W. H. Hoecker, Jr, 1975, "Relative Diffusion within the Los Angeles Basin as Estimated from Tetroon Triads," J Appl Meteorol, 14(8):1490-1498

[66] R. B. Husar et al, 1977, "Three-Dimensional Distribution of Air Pollutants in the Los Angeles Basin," J Appl Meteorol, 16(10):1089-1096

Mexico City, Mexico

Urban meteorology data for Mexico City seems to be limited to 30 climatological stations within or near the city.[67] Continuous records of wind and temperature are not available. In addition, several mobile traverses of the city for revealing the magnitude of the heat island have been done.

Nagano, Japan

The heat island of Nagano was studied by Sekiguti from November 8 to November 13, 1972. Maximum and minimum temperatures were measured at 38 sites in Nagano.

Oklahoma City, Oklahoma

Some limited balloon and tower data exist for Oklahoma City. Primarily observations are via tetroon balloons of which 56 overflew the city between September 25 and October 12, 1971.[10 68] The tetroons were flown in three parts of the day; 0900 to 1200 LST, 1200 to 1800 LST, and 1800 to 2100 LST.

Tetroon range, azimuth, and elevation angle was stored at 1-s intervals on magnetic tape. Later it was averaged over 30-s intervals. On September 28, 29, and 30 there were releases of pilot balloons every 6 min over 2-h observation periods.

In addition, tower winds at 355, 177, or 44 m are available. Temperatures and winds at eight levels on the 444-m tower are available from the National Severe Storms Laboratory. The tower is located just north of the city.

Paris, France

Paris is one of the largest and densest urban areas in the world. The 1975 population is estimated to have been 8,000,000 in an area of 1000 km^2. Meteorological observations have been made in the city since 1683, however, the number of stations is limited.[69] There are two regularly reporting stations in the urban area and seven in the surrounding countryside. Each station measures wind direction, windspeed, temperature, relative humidity, dewpoint temperature, and cloud cover. Solar radiation is measured by one station within Paris. Tower data is limited to isolated reports from the Eiffel tower.

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[67] E. Jauregui, 1973, "Urban Climate of Mexico City," Erdkunde, 27:298-307

[10] J. K. Angell et al, 1973, "Urban Influence on a Strong Daytime Flow as Determined from Tetroon Flights," J Appl Meteorol, 12:924-936

[68] J. K. Angell and A. B. Bernstein, 1975, "Flow Across an Urban Area Determined from Double-Theodolite Pilot Balloon Observations," J Appl Meteorol, 14:1072-1079

[69] J. Dettwiller, 1978, "L'évolution Séculaire de la Température à Paris," La Météorologie, VIe Série No. 13:95-130

Plymouth, England

Mobile transects of wind and temperatures were made in Plymouth twice daily from March 12 to March 15, 1973.[70] The transects were made at about 0700 and 1300 local time throughout the city and environs. The data is supplemented by 11 fixed stations in the area. No additional data to reveal vertical profiles was taken.

Rome, Italy

Various urban meteorological data have been collected in and around Rome.[71] * There has been a station collecting meteorological data at the same location since 1782. This observatory belongs to the "Ufficio Centrale di Ecologia Agraria" of the Italian Agriculture Department. Only surface data are available and include: windspeed and wind direction, relative humidity or dew point, cloud cover, temperature, and precipitation.

On a 1977 program, an aircraft equipped with a psychrometric probe surveyed the vertical extent of the urban heat island to an altitude of 500 m. In conjunction pibals were released at three points around Rome.

In the city and its surrounding areas there are also many other stations that collect surface data; they belong to a variety of services. A vertical sounding is taken at Leonardo da Vinci airport, which is about 20 km away from the center of the city.

In addition, meteorological surveys to characterize the urban heat island have been done. Generally the duration of these surveys has been limited to a few days.

San Francisco Bay Area

The Bay Area Air Quality Management District (BAAQMD) makes routine meteorological measurements at a large number of stations in the bay area. The data collected includes windspeed and wind direction, solar insolation, temperature, and cloud cover. Data collected from 1969 through March 1982 have been stored on magnetic tape. Unfortunately, relative humidity data is only available in strip chart form.

Upper air data have been collected at 20 locations in the bay area over the years. During October 1976, nine of these stations were in operation for one day. Measurements appear to have been made in the late afternoon or early afternoon hours. Various agencies have archived the data.

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[70] G. E. Millward and R. H. Motte, 1976, "Observations of the Plymouth Temperature Field," Weather, 31:255-260

[71] M. Colacino, 1980, "Some Observations of the Urban Heat Island in Rome During the Summer Season," Il Nuovo Cimento, 3C(2):165-179

*M. Colacino, 1982, personal communication

Stuttgart, Germany

Stuttgart is a city of approximately 600,000 people and is located in southwestern Germany on the Neckar river valley, which is about 200 m deep. Parts of outlying Stuttgart lie on relatively flatter ground away from the city, while most of the central city is located in the valley or along the valley walls.

Observations at Stuttgart consist of seven surface wind and temperature stations whose locations incorporate the city terrain variations.* Unfortunately, the stations are separately run by city, state, and federal governmental agencies. Three stations are administered and archived by the city, two by the state of Baden-Württemburg, and two by the Federal Republic of Germany.

Tokyo, Japan

Various studies of the urban climate of Tokyo have been performed. Tsuchiya[72] observed the Tokyo surface temperature by airborne remote sensing on four sunny summer afternoons. Quite remarkable variations were found. Meteorological data from 12 stations around Tokyo were used to analyze the urban climate and its changes in the past 50 to 60 yr.[73]

Winds were measured on the 333-m Tokyo tower[74] in downtown Tokyo. Fast response and slow response anemometers were located on the west side of the tower at 26, 67, 107, 173, and 253 m. Fast response anemometers were located on the east side of the tower at 26, 107, and 253 m; wind vanes were located on the west side at 107 and 253 m; and on the east side at 26 m.

Toronto, Ontario

Toronto has a population of nearly 3,000,000 in an area of 2300 km^2. The city is on Lake Ontario which considerably influences the climate. In addition, the terrain rises steadily from the lakeshore northward so slope winds are likely to be an additional influence.

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*J. Keller, 1982, personal communication

[72] Iwao Tsuchiya, 1974, "Some Features of the Urban Environment of Tokyo by Remote Sensing of Ground Surface Temperature," Papers in Meteorology and Geophysics, 25(3):147-158

[73] I. Maejima et al, 1980, "Recent Climatic Change and Urban Growth in Tokyo and its Environs," Essays in the Geography of Tokyo, Geographical Reports of Tokyo Metropolitan University, 14/15:27-48

[74] H. Arakawa and K. Tsutsumi, 1967, "Strong Gusts in the Lowest 250 m Layer over the City of Tokyo," J Appl Meteorol, 6:848-851

Studies of the Toronto urban effect have dealt with maximum and minimum temperatures from cooperative observers and automobile traverses in the Toronto area.[75] The induced heat island mesocirculation was studied with data obtained from 13 anemometers located around metropolitan Toronto at a 10 m height.[76] The sources of data include Toronto area Canadian Tower sites. The four Toronto towers are summarized below:

Name	Height (ft)	Site	Anemometer	Data Collection
CBC Tower	340	Urban	Bendix-Friez	10 min avg, hourly
Met Research Station	635	Rural	Bendix-Friez	10 min avg, hourly
Mimic	350	Suburban	Bendix-Friez	10 min avg, hourly
Scarborough	550	Suburban	Bendix-Friez	10 min avg, hourly

Generally each tower has two levels of wind and temperature data. Finally, there is the regular synoptic pilot balloon release at the Toronto Airport.

Tsukuba, Japan

Routine hourly observations have been made at the hydrometeorological observation field at the University of Tsukuba since 1977.[77] The city of Tsukuba has a population of 133,721 within an area of 28,520 hectares. The observations were made on a large field with a meteorological tower located in the middle.

Observations made at the 1.6, 12.3, and 29.5 m levels included windspeed and wind direction, temperature, and dewpoints. The data is available on computer tape or computer tabs. Synoptic charts for the observation period and land use maps for the area for 1970 and 1975 can be procured from the Japan Meteorological Agency.

The instruments include: sonic anemometer, thermometer, resistance thermometer, dewpoint thermometer, heat flux plate, pyrheliometer, net radiometer (Middleton, Beckman), evaporation pan, weighing lysimeter, and rain gauge.

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[75] R. E. Munn, M. S. Hirt and B. F. Findlay, 1969, "A Climatological Study of the Urban Temperature Anomaly in the Lakeshore Environment, Toronto," J. Appl. Meteorol, 8:411-422

[76] B. F. Findlay and M. S. Hirt, 1969, "An Urban-Induced Meso-Circulation," Atmos Environ, 3:537-542

[77] Information Pamphlet, 1980, Environmental Research Center, University of Tsukuba, 8, Japan

The observation field is circular with a radius of 60 m and is covered by 50 cm of tall grass. The tower is at the center of the field. The neighboring area includes some buildings and forests which are about 30 m tall.

Utrecht, The Netherlands

The urban climate of Utrecht was studied during December 1969, and January and February 1970.[78] At that time, Utrecht had a population of 276,000 in an area of 52 km^2. Utrecht is about 30 mi inland and should be largely unaffected by the sea breeze. The Netherlands is a very densely populated country, so isolation of Utrecht from nearby urban areas such as Amsterdam, Rotterdam, s'Gravehage (The Hague), Arnhem, and Haarlem is limited. On the other hand, European cities do not have the urban sprawl that is common in the United States. Just outside the city limits in European cities one finds pastoral scenes. The environs of Utrecht are extremely flat. The study of Utrecht took 3 forms; auto traverses, rural-urban comparisons of temperature, and vertical temperature profiles in the city.

Auto traverses were the main means of observation. Traverses began at 7:30 Middle European Time (MET) when it was still dark in the Netherlands and lasted about 1-1/2 h. A second traverse was begun at 1300 MET. The temperature equipment consisted of four thermocouples mounted on top of a VW van at 0.5-m intervals. Readings were recorded on a "Servogor" strip chart recorder.

The urban-rural temperature comparison consists of two thermographs, one urban and one rural. The urban site was located in a garden in the city center. The rural site was at the Royal Netherlands Meteorological Institute (RNMI) 4 km from the city center. Hourly observations of temperature, wind, relative humidity, and sunshine are available on punched cards from the RMNI. There is also the synoptic radiosonde balloon that yields a low altitude wind at 200 m. Finally, the 100 m dome on a cathedral in central Utrecht was outfitted to show temperature profiles. The sensors were electrical resistance thermometers with an accuracy of $\pm 0.1°C$. Measurements were made on only a few days.

Venice, Italy

Wind data at three locations around Venice was collected during February, March, and April 1973.[79] Spectral analyses of both the wind data and sulfur dioxide concentrations were done.

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[78] L. A. Conrad, 1975, "Observations of Meteorological Urban Effects, the Heat Island of Utrecht," PhD Thesis, University of Utrecht, the Netherlands

[79] F. Mattioli, 1977, "Spectral Analysis of Wind and SO_2 concentration in the Venice Area," Atmos Environ, 11:113-122

Vienna, Austria

Vienna has a population of 900,000 in an area of 300 km². Its metropolitan population is 1,600,000 in an area of 1000 km². Location is 48°N and 16°E. Vienna has made and archived surface meteorology measurements since 1968.[80] A total of 26 stations (16 urban and 10 rural or suburban) are included. Both surface wind and temperature are measured at these stations. Temperatures are recorded only 3 times a day and are archived on tables.

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Vertical temperatures were measured on two towers during the winter months.[81] The one tower is the 252-m high Donauturm which is located near the Danube river. Temperatures there were measured at 2, 35, 75, 112, 185, and 225 m above the ground. The 137-m Stephansturm is 4.8 km away. Temperatures were measured at 5, 50, and 110 m above ground.

Washington, DC

A cooperative network of over 200 observers take temperature measurements once daily in the Washington metropolitan area. The observations are taken at the same time and are archived on cards.

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National Weather Service
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Winnipeg, Manitoba

A 1-yr sample of wind (Bendix-Friez aerovanes) and temperature data at 11, 17, 37, 61, 122, 183, and 247 m is available from a 250-m tower. The tower is located 20 mi west southwest of Winnipeg in a flat rural area.

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[80] R. Böhm and K. Gabl, 1978, "Die Wärmeinsel einer Großstadt in Abhangigkeit von Verschiedenen Meteorologischen Parametern," Arch Met Geoph Biokl, Ser. B, 26:219-237

[81] A. Machaleck, 1974, "Das vertikale Temperaturprofil über der Stadt Wien," Wetter und Leben, 26:87-93

Cities With Limited Urban Data

Albuquerque, New Mexico	Regina, Saskatchewan
Brisbane, Australia	Saskatoon, Saskatchewan
Charlotte, North Carolina	Seattle, Washington
Chattanooga, Tennessee	South Bend, Indiana
Cleveland, Ohio	Sydney, Nova Scotia
Duluth, Minnesota	Tallahassee, Florida
Halifax, Nova Scotia	Tampa, Florida
Miami, Florida	Toledo, Ohio
Milwaukee, Wisconsin	Tucson, Arizona
Nashville, Tennessee	Wichita, Kansas
Omaha, Nebraska	York, Pennsylvania
Portland, Maine	

Albuquerque, New Mexico

Data collected by the local air pollution control division consists of wind data at three sites. At one site, the data is recorded monthly on diskettes for an IBM 5110 computer. Data is available from January 1981 to present. At the other two sites, data is recorded on strip charts. In addition, there are the regular NWS observations.

Brisbane, Australia

Daily data and/or monthly averages are available for Brisbane City (0900 and 1500); Brisbane Airport (Eagle Farm - three hourly midnight to midnight); and Amberley Royal Australian Air Force Base (three hourly, 0300 to 2100). Upper wind data is available for Brisbane Airport at six hourly intervals; at 0300, 0900, 1500, and 2100; radiosonde data at Brisbane Airport is available 0900 only. For Brisbane City, three hourly data (midnight to midnight) are available from 1957 to October 1973; however, no computer data before 1957 is held. All above data are available on computer printout or magnetic tape. Details of tapes:

9 channel, EBCDIC coding, 800 bits/in

or

7 channel, BCDIC coding, 556 bits/in, both 8 bits character.

Chattanooga, Tennessee

The only reliable data is taken by the NWS at Lovell Field. Other meteorological stations have questionable reliability due to siting, calibration, or maintenance.

Cleveland, Ohio

Data for Cleveland appears limited to the NWS station at Cleveland Hopkins International Airport. During the early to mid-1970s hourly wind data from one monitoring site was reduced and sent to the Ohio EPA.

Duluth, Minnesota

Data are limited to the NWS station at Duluth International Airport.

Halifax-Dartmouth and Sydney, Nova Scotia

Data for these two cities is limited primarily to climatological data available from Atmosphere Environment Canada on magnetic tape. Some data covering short periods for vertical wind and temperature profiles have been acquired using minisondes.

Miami, Florida

Dade County only collects wind data. All other data is obtained from the NWS.

Milwaukee, Wisconsin

Data for Milwaukee is limited to three surface stations. At these stations wind, temperature, and dewpoint are observed continuously. The data is available as far back as 5 yr. The equipment specifications are listed below:

Windspeed	Climet M/#011-23
Wind direction	Climet M/#012-6C
Dewpoint	Climet M/#015-12
Temperature	Climet M/#015-3

The windspeed threshold is 1.25 mi/h with an accuracy of 0.25 mi/h. Wind direction threshold is 1 mi/h with an accuracy of ±1 percent. Temperature error is less than 0.0025 percent/F°. No vertical profiles are available.

Portland, Maine

Meteorological data for Portland appears limited to continuously recorded wind direction and windspeed at 50 ft above ground level at one site in a residential area. In addition there is the NWS station at the airport.

Regina and Saskatoon, Saskatchewan

The only data available for Regina and Saskatoon, Saskatchewan, is hourly data taken at each cities' airport. Wind direction and windspeed at 10 m above ground, temperature, dewpoint, and cloud cover are all available on magnetic tape from Atmospheric Environment of Canada whose address is given elsewhere in this report.

Seattle, Washington

The Puget Sound Air Pollution Control Agency makes wind measurements at five locations in and near Seattle. The data are available on magnetic tape.

Tallahassee, Florida

The NWS collects data for Tallahassee airport at a location well outside the city. The local Air and Water Pollution Control also collects wind data from a single urban site.

Tampa, Florida

For Tampa, Florida, with a population of 473,680 (1967) there is summarized data available for 1931 to 1967. The data consists only of daily measurements of wind direction and windspeed at two locations, in addition to Pasquill stability categories and mixing depths.

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Toledo, Ohio

Data for Toledo is limited to a station collecting wind data continuously for the Ohio EPA and the NWS station at Toledo-Express Airport.

York, Pennsylvania

York does not currently take meteorological measurements. Local data is recorded by the York Water Company and submitted to the NWS. Measurements are taken outside the urban area.

LAND USE CLASSIFICATION

Numerous studies have shown the meteorological conditions in an urban area are considerably different from those in surrounding rural areas. Many of the differences owe their existence to the variation of land use between urban and rural areas. While the rural surface primarily consists of tree and grass cover, the urban surface contains a mixture of buildings, pavement, grass, and trees. A useful goal is a land use classification based on the boundary layer effects of the urban surface.[82]

The various urban effects on the boundary layer can be considered due to the roughness, radiation characteristics, and anthropomorphic heat generation of the urban surface. Roughness depends upon building heights, densities, and ground cover. Radiation characteristics involve the surface heat emissivity, absorptivity, heat capacity, and availability of moisture. Anthropomorphic heat generation depends on the season and attendant weather conditions. The most measurable of the above is roughness. Radiation characteristics will vary from building to building and probably over individual buildings. At this point, only a very coarse resolution of radiation characteristics can be attempted. Anthropomorphic heat generation is certainly beyond the scope of this work. Roughness thus seems the most appropriate consideration for land use classification.

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[82]A. H. Auer, Jr, 1978, "Correlation of Land Use and Cover with Meteorological Anomalies," J Appl Meteorol, 17(5):636-643

A usable urban land use classification must attempt to resolve the variation of urban land use under the constraint of available time and effort. Furthermore, the smallest scale of land use variation ought to be based on its effect on the urban boundary layer. The boundary layer cannot respond to the smallest scales of land use variation. For these reasons, a resolution of 100 m was selected for areas near the core regions in both St. Louis and Uppsala. For other areas, a resolution of 200 m was used.

There are several other important considerations for a land use classification. The need to resolve different types of land use must be balanced by a workable number of classifications.[83] From an original 21 land use classifications, 15 classifications were derived to adequately resolve the variation of the urban surface. The various classifications are based primarily on roughness height considerations such as trees versus grass, and buildings versus pavement. Some radiation considerations such as parking lot or road versus grass are also incorporated.

These considerations include whether or not buildings are present in urban areas. If they are, what is their height and what percent of the area do they cover? For rural areas the considerations include whether the land is open or forested. Radiation considerations involve the predominating type of surface in open land. The various surfaces include pavement, water, grass, or trees.

The derived classifications that are described in the next section are similar to Auer's land use classifications. More importantly, since they are derived from Ellefsen's work they are consistent with other Army land use classification schemes. This consistency will facilitate use of this scheme and attendent microscale meteorology relations linking boundary layer wind and temperature profiles to land use.

URBAN ZONE CLASSIFICATION

The rationale for classifying urban zones arose from consideration of their function, location, measurable characteristics, and historical origin. As a result several general groups of urban zones can be distinguished and they are shown in table 6.

For each general group above, one or more classifications may apply. At present, a total of 15 classifications are used. Originally there were 21 classifications, but some were combined as their meteorological effect was deemed similar. At the same time two new classifications were necessary.

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[83]R. Ellefsen et al, 1981, "Urban Terrain Analysis Training Aids," Technical Memorandum 14-81, Final Report for Contract DAAK11-79-C00085, TRASANA, White Sands Missile Range, NM

TABLE 6. URBAN ZONES

I. Commercial
(office, retail goods and services)

II. Administrative/Cultural

III. Residential

IV. Industrial/Storage

V. Non Built-upon
(parks, athletic fields, cemeteries, railroad yards, airport runways)

Classifications A, B, C, and D of table 7 apply to the commercial area of the city. A and B chiefly occur in the Central Business District (CBD) while C may be in the CBD and beyond. Classification A includes the part of the CBD with high rise buildings. In general, ten stories and above was the differentiation between A and other classifications. Classification B also includes the CBD with medium to high rise buildings of five to ten stories. Examples are core and contiguous areas of commercial buildings and apartments. Classification C includes commercial and apartment buildings, and row housing. Classification C buildings are less than five stories high. Classification D has its roots in the recent development of satellite core areas away from the CBD. A classification D area consists of buildings of ten or more stories.

Classification C*, E, and E* involve urban areas with low building density and low to medium rise buildings. Classification C* is for areas which seem to apply to both classification C or E. It was not intensively used. Classification E includes a number of urban areas that have low density and low to medium rise buildings. A number of urban areas apply such as colleges and schools, stadiums, shopping malls, truck related industries, and parking lots. In effect, E is distinguished on the basis of building density. Classification E* includes core areas that have a very low building density without parking lots. They are chiefly areas of urban renewal with abandoned lots.

The residential group consists of three classifications; F, G, and H. Classification F consists of planned unit developments such as apartments away from the CBD. Classifications G and H involve residential housing. When the distance between houses is less than or equal to the house widths, classification G was assigned, and where the distance is larger, classification H was assigned. Since G classification housing appears to present favored avenues to wind channeling, the orientation of the G housing in the four directions N, NE, E, SE was given where possible. Only four directions are necessary since the direction analogues S, SW, W, and NW are equivalent in wind channeling effect.

The industrial classifications are I, II, and J. Classification I refers to industrial storage in the form of ordered city blocks. An example is the warehouse section of a city not associated with docks or not aligned along rail lines. There is no preferred channeling of wind for classification I. Classification J includes industrial areas that have a preferred orientation such as docks and railways associated structures. As for G, the orientation

TABLE 7

LAND USE CLASSIFICATIONS

Classification	Description
A	Central Business District (CBD), commercial and apartments, high rise.
B	CBD and contiguous, commercial and apartments, medium to high rise.
C	CBD and beyond commercial and apartments, row housing, low to medium rise.
D	Outlying office or apartment cluster, high rise.
E	Low density, low to medium rise, among parking lots and other nonbuilt-upon areas. Colleges and schools, stadiums, shopping malls, truck related industries, and parking lots.
E*	Low density areas without parking lots, areas of urban renewal.
F	Residential planned unit developments, apartments.
G	Residential housing with orientation ratio of side to gap 1 or less.
	GN North or south.
	GNE Northeast or southwest.
	GE East or west.
	GSE Southeast or northwest
H	Detached houses, gap to front ratio greater than 1.
I	Industrial storage, ordered city blocks, usually adjacent to CBD.
I1	Large industrial plant covering several acres.
J	Industrial storage, rail and docks, linear orientation, with orientation as for G.
K	Nonbuilt-upon - grass dumps and junk yards.
L	Nonbuilt-upon forest. Trees cover more than 50% of area.
M	Water

in the four directions is given. Some industrial buildings are quite huge. Il refers to industrial buildings that cover several and sometimes many blocks.

Nonbuilt-upon areas include grass, tree, and water areas. The respective classifications are K, L, and M. Classification K includes all nonbuilt-upon areas in which grass is predominant as well as dumps and junk yards. Classification L includes nonbuilt-upon areas in which trees predominate. The cut-off for classification L versus K was on the basis of 50 percent or greater coverage with trees. Finally, classification M includes all areas of water such as lakes, larger rivers, and the ocean. The classifications and their descriptions are summarized in table 7.

PROCEDURE

The land use classification of St. Louis and Uppsala proceeded generally in three parts. The first part was the procurement of aerial survey photographs and topographic maps for both cities. In the case of Uppsala, the National Land Survey of Sweden provided excellent aerial photos and maps. A number of private and public concerns provided the St. Louis photos and maps; among these were the St. Louis County Department of Planning and the city of St. Louis Community Development Agency. Where possible photos on a scale of 1 in = 400 ft and maps on a 1:24,000 scale were obtained.

The second part involved examining the aerial survey photographs and selecting the appropriate land use classification. In core commercial districts, the examination considered land use on a 100-m scale; at such a scale virtually all features were resolved. Away from core areas, the examination proceeded on a 200 m scale.

In the final part, the selected classifications were entered on the topographic maps. For St. Louis, the letter codes were used. As the Uppsala topographic map scale was less than that for St. Louis, a color coded classification scheme was used and entered on an overlay background.

Examples of Land Use Classification

The city of Uppsala, Sweden is a relatively small university town located about 100 mi northwest of Stockholm. Most of the urban land use classifications occur within Uppsala. In figure 6 the results of the land use classification of Uppsala are shown. Apartment or row housing land use is more prevalent in Uppsala than in St. Louis, while industrial land use is considerably less. In addition there are no high rise buildings of any type in Uppsala. Completely surrounding Uppsala is unbuilt-upon land consisting of fields and forests.

SELECTION OF UPPSALA AND ST. LOUIS

From the large number of observational programs, the RAPS in St. Louis and the UUMP in Uppsala were selected for incorporation to the urban meteorology data base. Both RAPS and UUMP satisfy all the criteria for selection. The criteria include temporal and spatial coverage, amount of data, its credibility, reliability, availability, and the land usage and terrain of the studied city. Inclusion of data from additional urban observation programs will be desirable in the future.

Figure 6. Land use classification of Uppsala, Sweden.

St. Louis is a good city to study the effect of the urban boundary layer for many reasons. St. Louis is intermediate in size between smaller urban areas that produce an observable urban effect and huge urban areas such as Tokyo. As such, RAPS data would be representative of the bulk of urban areas in terms of the urban effect on meteorological conditions. In addition, the work necessary to process St. Louis is considerably less than what would be necessary for New York or Tokyo. Finally, all the types of land use introduced previously occur in St. Louis.

Another important reason for selecting St. Louis is its relatively simple terrain. Because of this, meteorological differences in St. Louis between rural and urban areas are mainly due to the urban effect. Identification of distinct urban effects is thus facilitated. Finally, the Metromex study that was also done in St. Louis offers a good future means for comparing results derived from analysis of RAPS data.

RAPS was primarily conducted and the data has largely been processed, documented, and archived by the EPA. The procurement of data can be greatly expedited when dealing with only one agency, as is the case here with the EPA. RAPS data is credible by virtue of reference and use in the meteorological literature and extensive documentation, and is extensive because of the number, type, and duration of observations. All the parameters required for the urban data base were measured during RAPS and to a large extent have been processed on magnetic tape. Finally, information concerning the land use in St. Louis is readily available.

Uppsala is also a good city for studying the urban effect. Because it is European, its land usage and consequently urban effect are somewhat different from that of North American cities. Uppsala data will thus incorporate variation not contained in the St. Louis data. While Uppsala is a small city, it is still large enough to have an urban effect. Inclusion of data from a small city further enhances the generality of the urban data base. In addition, the terrain around Uppsala is essentially flat and the city lies well away from the sea. As for St. Louis, the urban effect can be readily discerned.

UUMP was conducted solely by the University of Uppsala and the data are archived at either that University or at the Swedish Meteorological and Hydrological Institute in Norrkoing. As contact with personnel familiar with UUMP at both sites has been established, the procurement of UUMP data is feasible. UUMP data are credible by virtue of reference in the literature and very extensive documentation. All of the desired urban data base parameters were extensively measured during UUMP and some of the data has been processed. Excellent information about the land use in Uppsala is also available.

The data from several other observation programs would be useful additions to the urban data base in the future. The studies done for Calgary and Edmonton Alberta, satisfy most of the urban data base requirements. The data from both studies has been declared available and considerable data processing has been done. While the NYAPP yielded extensive data that has been extensively processed, it might prove burdensome to attempt to deal with this amount of data. Effects other than urban are important contributors to the meteorological conditions in New York.

There are several other creditable urban observation programs that were done for Columbus, Ohio; Ft. Wayne, Indiana; Las Vegas, Nevada; Johannesburg, South Africa; and Montreal, Quebec. Most of these programs' data are unprocessed, and inclusion to the urban data base would constitute a very time-consuming and expensive task.

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